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Butadiene Measurement Technology

Southwest Research Inst., San Antonio, TX

Prepared for

Environmental Protection Agency, Ann Arbor, MI

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Butadiene Measurement Technology

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Work Assignment B-1

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FOREWORD

This project was conducted for the U.S. Environmental Protection Agency by the Department of Emissions Research, Southwest Research Institute. The program, authorized by Work Assignment B-1 under Contract 68-03-4044, was initiated June 11, 1987 and completed in February 1988. It was identified within Southwest Research Institute as Project 08-1567-001. The EPA Project Officer for the program was Mr. Craig A. Harvey of the Emission Control Technology Division, Ann Arbor, Michigan. SwRI Project Leader and principal researcher for the project was Dr. Lawrence R. Smith. Mr. Charles T. Hare was Project Manager, and was involved in the initial technical and fiscal negotiations and subsequent major program decisions.

ABSTRACT

This program involved the development and validation of a gas chromatography procedure to measure 1,3-butadiene levels in vehicle exhaust. After development and validation, the procedure was used to measure 1,3-butadiene emissions from each of two gasoline-fueled light-duty test vehicles over duplicate cold-start FTP tests. The 1,3-butadiene emissions are reported in mg/mile and as total grams for each FTP test. In addition to the 1,3-butadiene measurements, regulated exhaust emission (HC, CO, and NO_x in g/mile), other C_4 hydrocarbon (n-butane, isobutane, etc. in mg/mile), and fuel economy (in mi/gallon) measurements were conducted for each FTP test.

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SUMMARY

An analytical procedure was developed and validated to measure 1,3-butadiene in dilute vehicle exhaust. This procedure utilizes a gas chromatograph (GC) with a flame ionization detector to separate 1,3-butadiene from butane and other C_4 hydrocarbons. Dilute exhaust samples are collected in standard CVS bags and analyzed within one hour of collection. The GC flame ionization detector gives a linear response for 1,3-butadiene in the region of interest. The procedure has a detection limit on the order of 0.03 ppmC 1,3-butadiene in dilute exhaust (0.5 mg/mile for the FTP). In addition to 1,3-butadiene, the procedure allows the quantification of six other C_4 hydrocarbons: butane, isobutane, 1-butene, isobutylene, cis-2-butene, and trans-2-butene. In this program the developed procedure was utilized to evaluate 1,3-butadiene emissions from two light-duty vehicles fueled with an alcohol-free commercial grade gasoline. The test vehicles, a 1986 Chevrolet Camaro and a 1987 Ford Taurus, were both fuel injected with closed-loop operation. The test fuel had a Reid Vapor Pressure of 12.05 psi and an olefin content of 13.6 percent.

The two test vehicles were each evaluated in duplicate over the Federal Test Procedure (FTP) with 1,3-butadiene, regulated emissions (total hydrocarbons, carbon monoxide, and oxides of nitrogen), emissions of six other C_4 hydrocarbons (butane, isobutane, 1-butene, isobutylene, cis-2-butene, and trans-2-butene), and fuel economy determined during each test. The most significant observations made from the data generated (not necessarily in order) are as follows:

- 1,3-Butadiene was detected in the exhaust of both test vehicles.
- The Camaro (port fuel injection) had a higher 1,3-butadiene emission rate than the Taurus (throttle body injection), 1.7 mg/mi versus 0.9 mg/mi.
- The 1,3-butadiene fraction of the total hydrocarbon emissions was higher for the Camaro than for the Taurus, 0.61 percent versus 0.36 percent.
- The majority (>98%) of the 1,3-butadiene emissions were generated in the cold-start transient phase (Bag 1) of the FTP. 1,3-Butadiene accounted for 0.70 percent of the Bag 1 Taurus hydrocarbon emissions and 0.95 percent of the Camaro hydrocarbon emissions.
- 1,3-Butadiene emissions were significant (0.35 percent of the total hydrocarbons), however, in the hot-start transient segment (Bag 3) of the FTP for a voided test on the Taurus. The Taurus had to be restarted several times during the initial segment of the hot-start test.
- In general, the Camaro had higher emission rates than the Taurus for the unsaturated C_4 hydrocarbons (1,3-butadiene, 1-butene, isobutylene, and trans-2-butene), while the inverse was noted for the saturated C_4 hydrocarbons (butane, isobutane).

I. INTRODUCTION

The objective of this program was to develop and validate a procedure for the measurement of 1,3-butadiene levels in vehicle exhaust. After development and validation, the procedure was used to measure 1,3-butadiene emissions from two gasoline-fueled light-duty vehicles. A measurement technique selective to 1,3-butadiene is important because previous sample collection and analysis techniques used for characterizing vehicle exhaust hydrocarbons did not permit the determination of 1,3-butadiene separately from butane, and because 1,3-butadiene has been determined to have high carcinogenic potency. This report describes the gas chromatography procedure that was developed and validated in this program for 1,3-butadiene exhaust measurements, and presents the results from two test vehicles.

The two gasoline-fueled light-duty vehicles tested in the program, a 1986 Chevrolet Camaro and a 1987 Ford Taurus, were rented locally. The Camaro had port (multipoint) fuel injection with a closed-loop 3-way catalyst and neither secondary air injection nor pulsed air. The Taurus had throttle body fuel injection with a closed-loop 3-way plus oxidation catalyst and pulsed air. Prior to testing, each vehicle was tuned to manufacturer's specifications and minor mechanical repairs were conducted, if required. The test fuel used in the program was a commercial grade unleaded gasoline obtained from a local service station. The test fuel had a Reid Vapor Pressure of 12.05 psi and an olefin content of 13.6 percent.

Each of the two test vehicles was operated in duplicate over the Federal Test Procedure (FTP) to generate exhaust samples for analysis. 1,3-Butadiene measurements, as well as measurements for six additional C_4 hydrocarbons (butane, isobutane, 1-butene, isobutylene, cis-2-butene, and trans-2-butene) and the regulated emissions (total hydrocarbons, carbon monoxide, and oxides of nitrogen), were made on each exhaust sample. 1,3-Butadiene and the other C_4 hydrocarbon results were reported in mg/mi and the regulated emissions results were reported in g/mi. Fuel economy determinations using the carbon balance method were also conducted with the results reported in miles per gallon.

II. GENERAL EQUIPMENT, INSTRUMENTS, PREPARATIONS AND PROCEDURES

This section describes the automobiles, the fuels, the facilities, and the general instrumentation and procedures utilized in this project. Sampling and analysis for 1,3-butadiene as well as butane, isobutane, 1-butene, isobutylene, cis-2-butene, and trans-2-butene are also discussed.

A. Automobiles

Two fuel-injected gasoline-powered automobiles were evaluated in this project. The automobiles are described in Table 1 and are shown in Figure 1. The 1986 Chevrolet Camaro was equipped with port (multipoint) fuel injection, and the 1987 Ford Taurus was California certified and equipped with throttle body injection. Both vehicles were rented locally. Prior to testing, the vehicles were tuned to manufacturer's specifications and operated over a cold-start FTP cycle to determine if the emission control systems on the vehicles were functioning properly. The Camaro appeared to be in acceptable operating condition (HC, 0.30 g/mi; CO, 4.56 g/mi; NO_x, 0.38 g/mi; and fuel economy, 22.22 mi/gal), but the Taurus was not operating properly (HC, 3.67 g/mi; CO, 115.12 g/mi; NO_x, 0.35 g/mi; and fuel economy, 17.98 mi/gal) and required some repair. Replacement of the fuel injector on the Taurus drastically reduced the HC and CO emission rates and increased the fuel economy (HC, 0.25 g/mi; CO, 3.35 g/mi; NO_x, 0.45 g/mi, and fuel economy, 23.68 mi/gal). At this point, the Taurus appeared to be operating properly and was accepted for use in the program.

TABLE 1. AUTOMOBILES EVALUATED

	Chevrolet Camaro	Ford Taurus
Model Year	1986	1987
Body Type	2-door	4-door
Engine Family	G1G2.8V8XGZX	HFM2.5V5HCH9
ID Number	G1FP8753GN119808	1FABP52D5HA157262
Odometer Mileage	33083	28568
Emission Controls	EGR/3CL	EGR/PLS/OXD/3CL
Fuel Injection	Port	Throttle Body
Transmission	L-4	A3
Chassis Dynamometer		
Inertia Setting, lbs	3,500	3,000
Power Setting, Horsepower	8.4	7.4

B. Test Fuel

The test fuel was an alcohol-free commercial grade unleaded gasoline (Gulf) obtained from a local service station. Selected properties of the test fuel are presented in Table 2. The test fuel had an RVP slightly higher than the requested 8.9 to 11.7 psi range (12.05 psi), however, its use was approved by the Project Officer. No. 1,3-butadiene was found in the test fuel.

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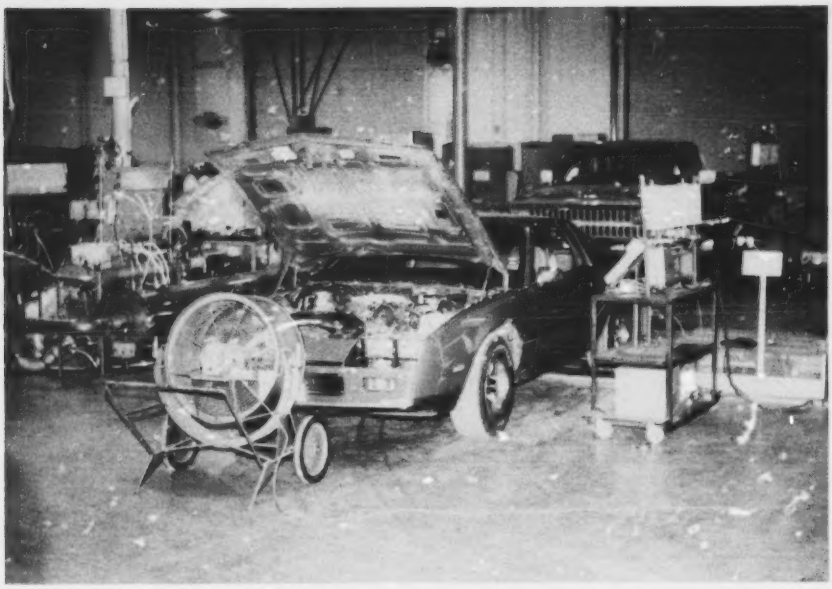

1986 Chevrolet Camaro

1987 Ford Taurus

FIGURE 1. AUTOMOBILES EVALUATED IN THIS PROJECT

TABLE 2. DESCRIPTION OF UNLEADED GASOLINE TEST FUEL, EM-781-F

Item	Test Result
Distillation - D86 °C(°F)	
IBP	23(74)
5%	32(90)
10%	38(101)
15%	43(110)
20%	49(120)
30%	60(140)
40%	73(164)
50%	88(191)
60%	106(223)
70%	115(239)
80%	148(298)
90%	171(340)
95%	189(373)
EP	207(405)
Recovery, %	98.5
Residue, %	0.5
F.I.A.	
% Aromatics	24.4
% Olefins	13.6
% Saturates	62.0
RVP, psi	12.05
Benzene, %	1.1
Toluene, %	4.0
Isobutane, g/gal	21
Butane, g/gal	140
1-Butene, g/gal	2.5
Isobutene, g/gal	1.1
cis-2-Butene, g/gal	7.2
trans-2-Butene, g/gal	7.9
1,3-Butadiene, g/gal	<0.3

C. Dynamometer and CVS Systems

A Clayton Model ECE-50 chassis dynamometer with a direct-drive variable-inertia flywheel system was utilized for the testing. This direct-drive inertia system simulates equivalent weight of vehicles from 455 kg (1,000 lb) to 4,025 kg (8,875 lb) in 55 kg (125 lb) increments. The constant volume sampler (CVS) used for the evaluations was SwRI CVS No. 2. An 18-inch diameter by 16-foot long stainless steel dilution tunnel was used in conjunction with the CVS, which was run at a

nominal 315 scfm. A cooling fan of 5,000 cfm capacity was used in front of the vehicles during all tests. Vehicle hoods were maintained fully open during the testing and were closed during the soak periods.

Partial views of the chassis dynamometer, the dilution tunnel, and the intake to the CVS can be seen in Figure 2. Both the dynamometer and the CVS were calibrated, maintained, and operated in accordance with the manufacturer's instructions and the appropriate sections of the Code of Federal Regulations applicable to light-duty vehicles.[1]*

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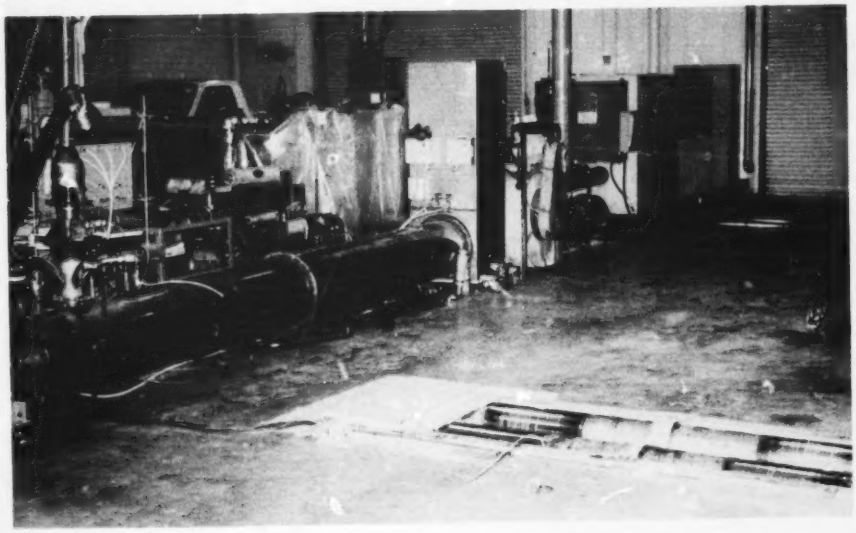

FIGURE 2. PARTIAL VIEWS OF THE CHASSIS DYNAMOMETER, THE DILUTION TUNNEL, AND THE INTAKE TO THE CVS

D. Instrumentation for Regulated Emissions

Bagged samples of the dilute exhaust were evaluated for HC, CO, NO_x, and CO_2 using SwRI Bag Cart No. 2. This bag cart was designed, calibrated, and operated in accordance with the appropriate sections of the Code of Federal Regulations applicable to light-duty vehicles.

E. Vehicle Test Procedure

The test procedure utilized in this project was the Federal Test Procedure[1] (FTP). The FTP uses the Urban Dynamometer Driving Schedule (UDDS) which is 1372 seconds in duration. The UDDS, in turn, is divided into two segments; the first having 505 seconds and the second having 867 seconds. The FTP consists of a cold-start 505 and a stabilized 867 followed by a ten-minute soak and then a hot-start 505. The FTP schedule is illustrated in Figure 3.

*Numbers in parentheses designate references at the end of the report.

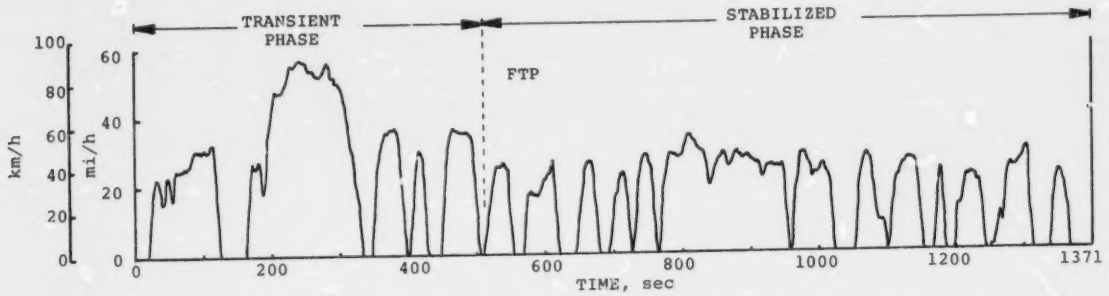

FIGURE 3. FTP DRIVING CYCLE VS TIME TRACE

F. 1,3-Butadiene Analytical Procedure

The analytical procedure used to measure 1,3-butadiene and several other C_4 hydrocarbons is summarized in this section. A detailed description of the procedure has been included as Attachment A of this report.

The procedure was developed to measure 1,3-butadiene in dilute vehicle exhaust. In addition to 1,3-butadiene, the procedure provides separation and exhaust concentrations for six other C_4 hydrocarbons including: isobutane, butane, 1-butene, isobutylene, cis-2-butene, and trans-2-butene. Standard CVS bag samples are analyzed for 1,3-butadiene using a gas chromatograph equipped with a flame ionization detector (FID). The gas chromatograph system utilizes a Perkin-Elmer Model 3920B gas chromatograph with an FID, two pneumatically-operated and electrically-controlled Seiscor valves, and an analytical column. The analytical column is a 9' x 1/8" stainless steel column containing 80/100 Carbopack C with 0.19% picric acid. The carrier gas is helium, which flows through the column at a rate of 27 ml/min. The column temperature is maintained at 40°C for analysis. External 1,3-butadiene standards in zero air are used to quantify the results. Detection limits for the procedure are on the order of 0.03 ppmC in dilute exhaust for 1,3-butadiene (0.5 mg/mile for the FTP).

III. PROCEDURE DEVELOPMENT AND VALIDATION

A selective measurement technique for 1,3-butadiene in dilute exhaust was necessary, because previous methods utilized in exhaust measurements did not permit the determination of 1,3-butadiene separately from butane[2], and because 1,3-butadiene had been determined to have a high carcinogenic potency. This section describes the development and validation of a gas chromatography procedure to accurately separate and quantify 1,3-butadiene emissions in vehicle exhaust.

A review of the literature and of currently in-use methods for the determination of 1,3-butadiene in complex hydrocarbon mixtures revealed that a number of gas chromatograph columns to separate 1,3-butadiene from butane and other C_4 hydrocarbons were commercially available. A Perkin-Elmer 3920B Gas Chromatograph equipped with a flame ionization detector (FID) and a gas phase injection system was utilized in the evaluation of these columns. The gas phase injection system allowed the analysis of standard CVS sample bags. The GC columns were either purchased from commercial distributors or prepared in-house using commercially available packing materials. A 6' x 1/8" SS column packed with 0.19 percent picric acid on 80/100 mesh Graphpac-GC gave promising results in the initial portion of the program. Figure 4 illustrates the separation obtained with the Graphpac Column. GC parameters for the analysis included an isothermal GC oven temperature of 30°C, an injection loop of 10 ml, an amplifier attenuation setting of x8, and a carrier gas (helium) flow rate of 40 ml/min. The GC parameters were then varied to optimize the GC response for 1,3-butadiene. The 2.6 ppmC 1,3-butadiene peak in Figure 5 was obtained by increasing the sample loop to 20 ml, increasing the oven temperature to 35°C, and changing the amplifier attenuation to x4.

A CVS bag sample (Bag 1) from the FTP testing of a 1987 Plymouth Reliant was analyzed for 1,3-butadiene. This analysis gave a 1,3-butadiene concentration in the dilute exhaust sample of 1.4 ppmC (Figure 6). This 1,3-butadiene concentration represented approximately 1 percent of the "cold-start 505" total hydrocarbons (147 ppmC). A second vehicle, a 1986 Chevrolet Celebrity (2.8 liter V-6 engine) gave approximately 0.2 ppmC in a Bag 1 FTP dilute exhaust sample. This concentration represented approximately 0.4 percent of the total hydrocarbons (46 ppmC). Mr. Craig A. Harvey, the EPA Project Officer for this program, was present during the Celebrity testing.

Mr. Frank Black of EPA-RTP was then contacted as to their approach for the analysis of 1,3-butadiene. The RTP laboratory also uses a stainless steel column packed with 0.19 percent picric acid on 80/100 mesh Graphpac-GC for the GC analysis of 1,3-butadiene. Differences in the SwRI and RTP procedures at this point included: 1) cryogenic concentration of the hydrocarbon sample at RTP as opposed to a 20cc sample loop at SwRI; 2) a longer analytical column at RTP, 9-foot compared to 6-foot at SwRI; and 3) naming of a 1,3-butadiene standard against propane on a total hydrocarbon FID at SwRI as opposed to naming the 1,3-butadiene on the GC-FID at RTP (differences in response factors for different hydrocarbons are greater on a total hydrocarbon FID than on a GC-FID). At this point, a certified low concentration 1,3-butadiene standard (2.0 $\pm$ 0.04 ppmC) was purchased from Scott Specialty Gases and utilized as a standard in subsequent test work. This standard also contained 8.04 $\pm$ 0.16 ppmC butane. To achieve additional separation of the C_4 hydrocarbons, a 9-foot x 1/8 inch SS column packed with 0.19 percent

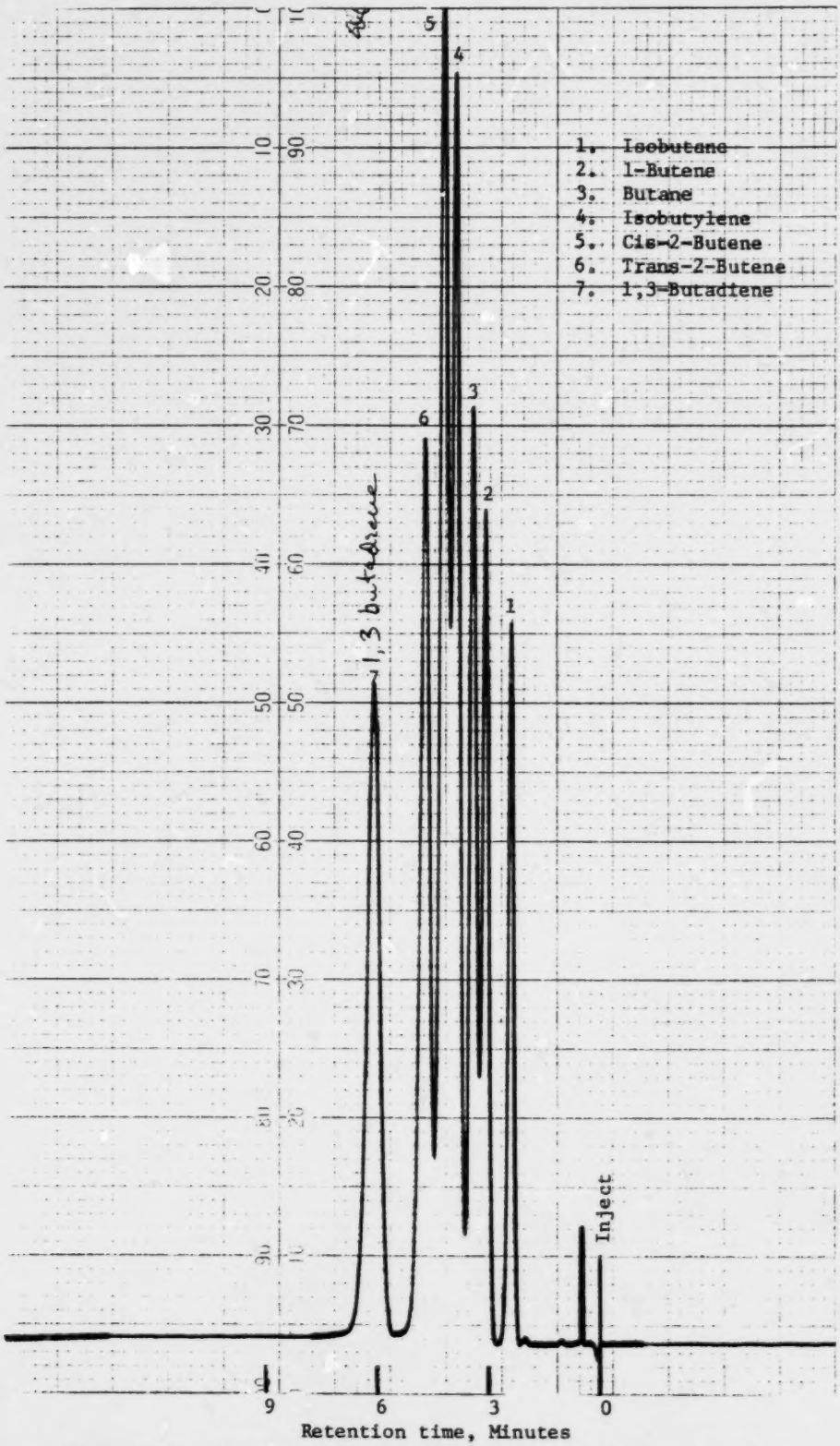

FIGURE 4. GAS CHROMATOGRAM OF C_4 HYDROCARBONS, ~25 PPMC EACH HYDROCARBON

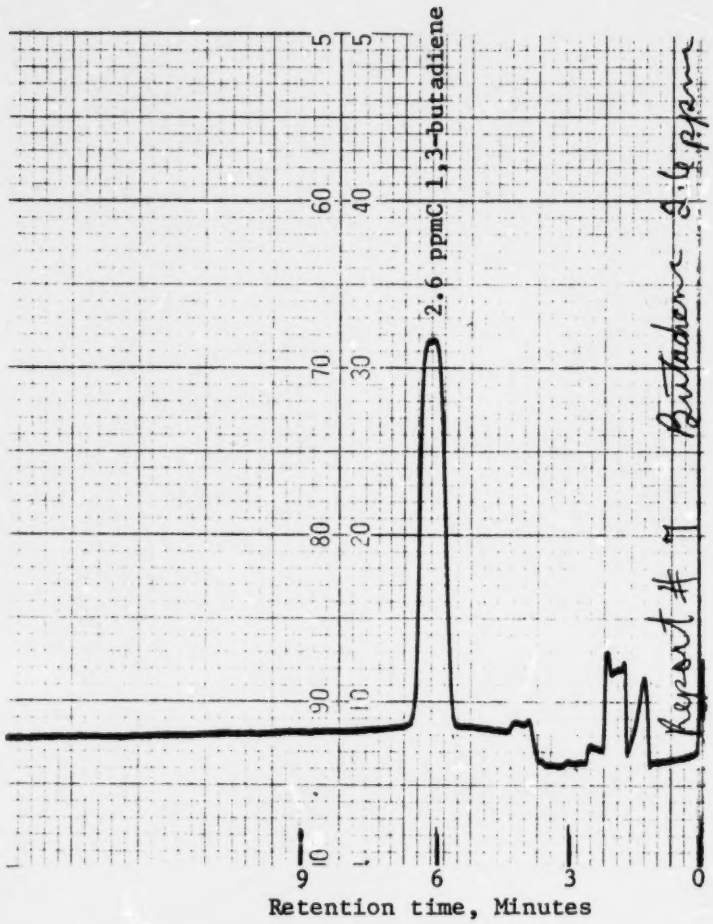

FIGURE 5. CHROMATOGRAM OF ~2.6 PPMC, 1,3-BUTADIENE STANDARD

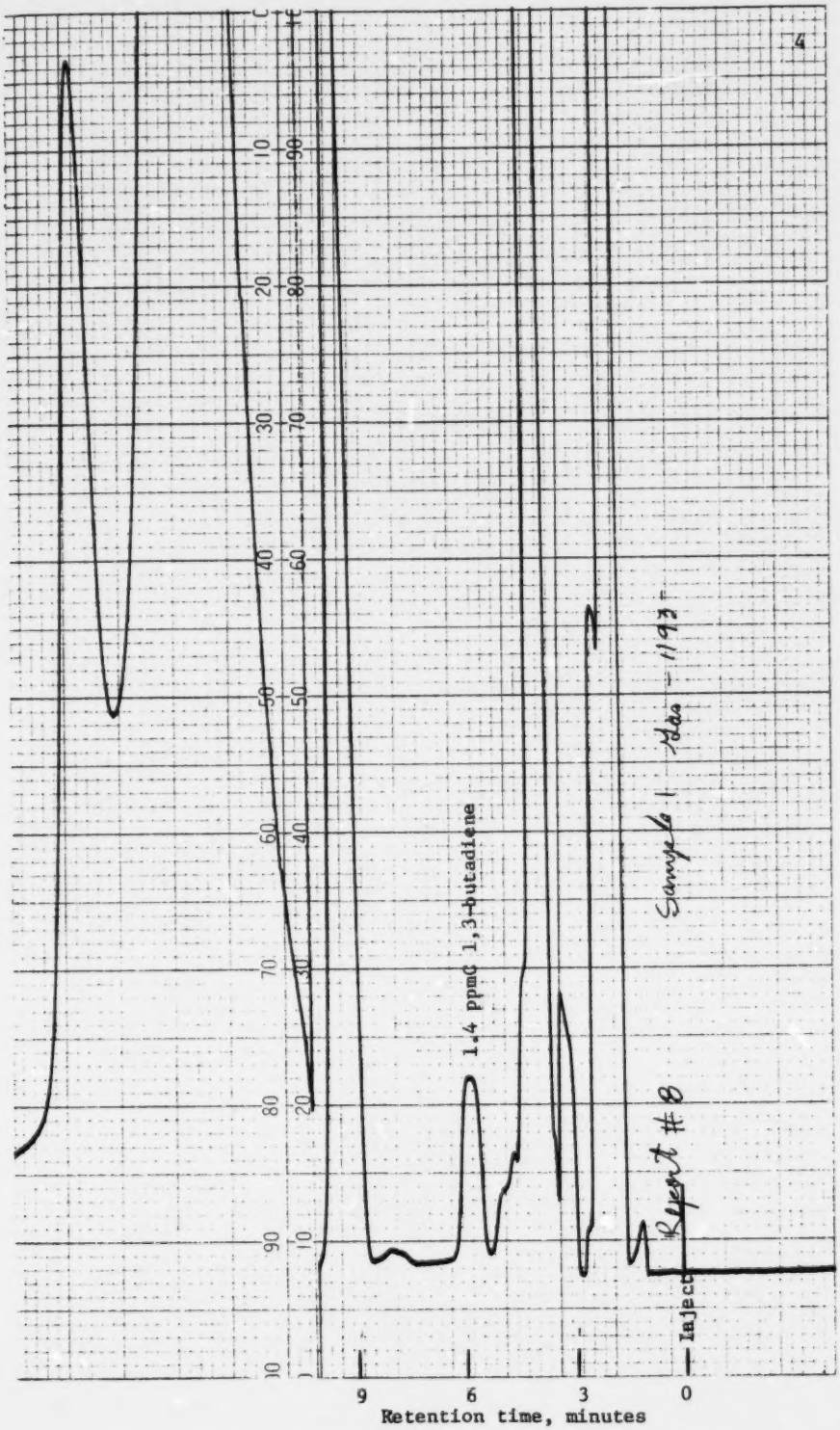

FIGURE 6. CHROMATOGRAM OF FTP - BAG 1 SAMPLE FROM 1987 PLYMOUTH RELIANT

picric acid on 80/100 mesh Carbopack C was prepared and installed into the GC to replace the existing six-foot column. With a carrier flow of 35 ml/min and an oven temperature of 35°C, this column provided a minimum separation of one minute between any two of the C_4 hydrocarbons. Figure 7 illustrates the separation of 1,3-butadiene and butane using the 9-foot column. A gas divider was used to dilute the standard to various levels in order to determine the linearity of the FID detector over the range of expected concentrations of both 1,3-butadiene (0-2.0 ppmC) and butane (0-8.04 ppmC) in dilute exhaust. The detector was found to be linear for both 1,3-butadiene and butane with r^2 values of 1.00 for both compounds. The data used to determine detector linearity can be found in Table 3. Figure 8 shows a chromatogram of a dilute exhaust sample (sample taken during the first 140 seconds of an FTP-bag 1). Seven C_4 compounds were separated and identified in the chromatogram. The identities of the butane and 1,3-butadiene peaks were confirmed by spiking the exhaust sample with the Scott standard. The remaining five C_4 compounds were identified by relative retention times.

TABLE 3. DETERMINATION OF DETECTOR LINEARITY

Gas Concentration in ppmC by Gas Divider(x)	GC Peak Area(y)
Butane	
8.04	69716
6.83	56045
4.02	33086
0.80	6821
0.0	0
8.04	69411
6.83	58070
$r^2 = 1.00$	
a = -426	
b = 8569	
1,3-Butadiene	
2.0	16532
1.7	13117
1.0	7528
0.2	1792
0.0	0
2.0	16346
1.7	13539
$r^2 = 1.00$	
a = -89	
b = 8080	

To determine 1,3-butadiene stability in exhaust, a cold-start 505 (bag 1) dilute exhaust sample from the FTP testing of a 1986 Chevrolet Celebrity (2.8 liter V-6 engine) was spiked with 1,3-butadiene. The sample bag was then analyzed for 1,3-butadiene immediately after the spike (time 0) and at 30, 60, 120, and 240 minutes

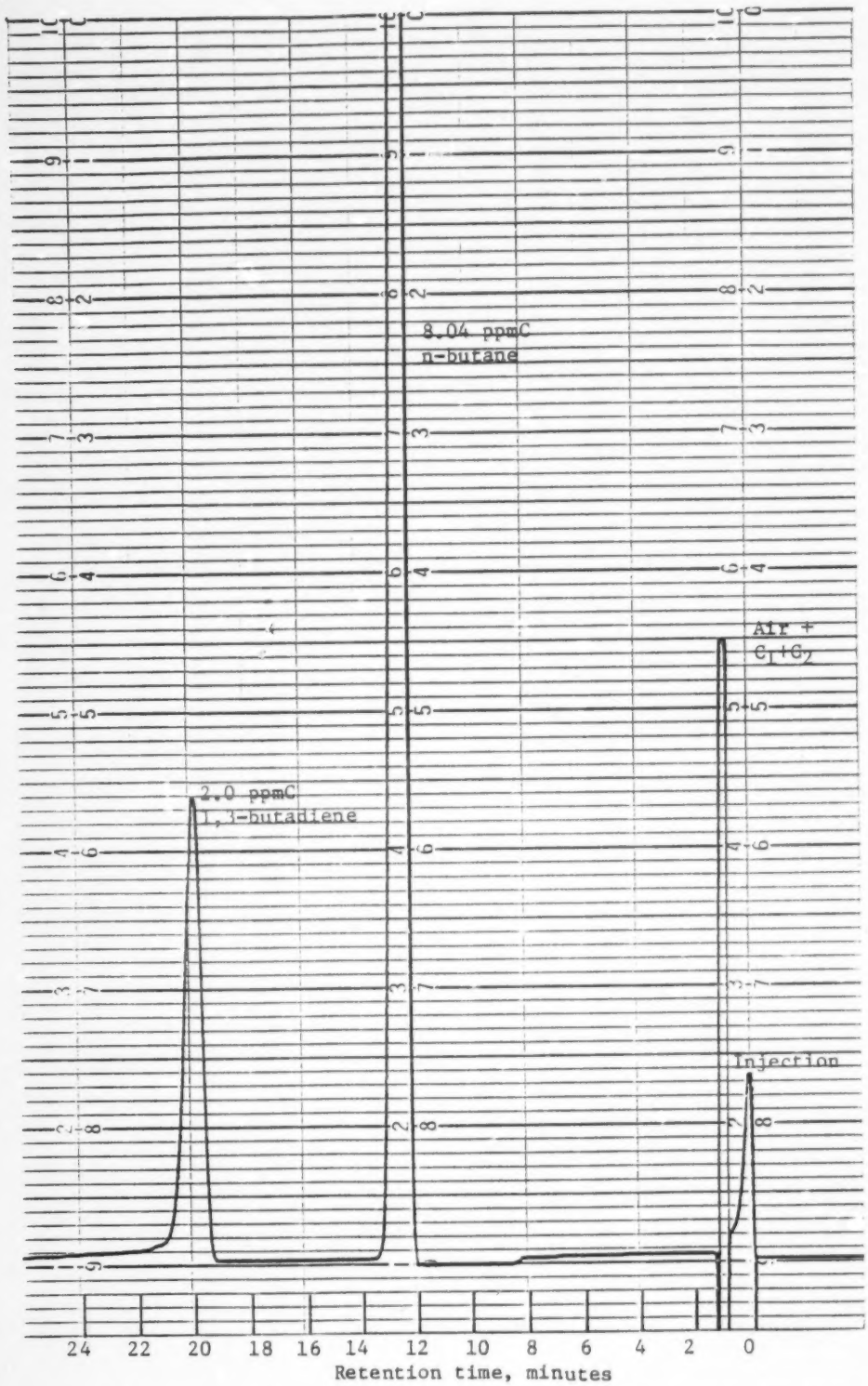

FIGURE 7. CHROMATOGRAM OF 1,3-BUTADIENE AND N-BUTANE STANDARD

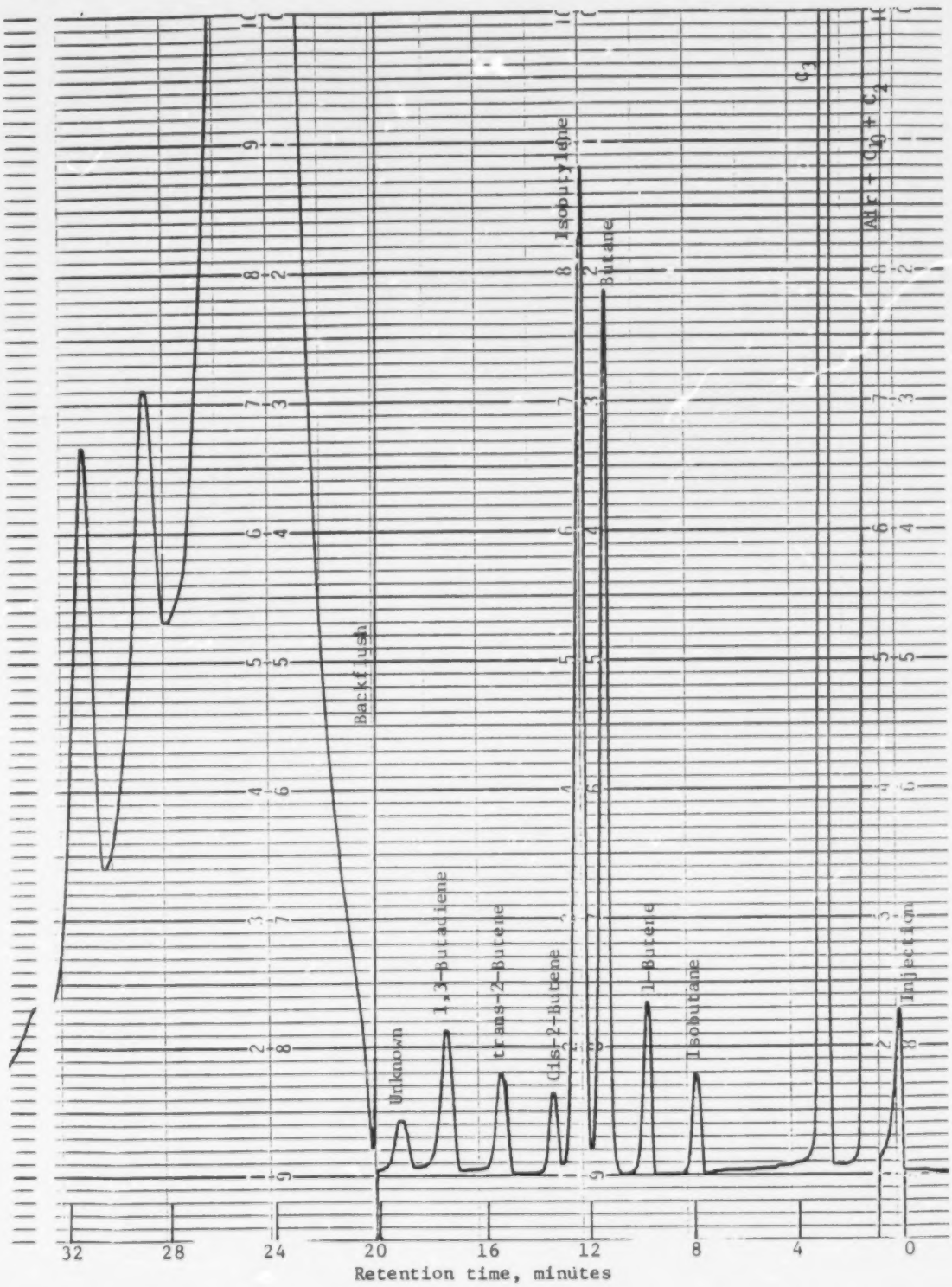

FIGURE 8. CHROMATOGRAM OF DILUTE EXHAUST SAMPLE

after the spike. Figure 9 displays the result of this experiment. The initial spiked concentration of 1,3-butadiene was on the order of 3 ppmC. After 4 hours, the 1,3-butadiene decreased to 63 percent of the original concentration. A 1,3-butadiene standard (<2.7 ppmC in nitrogen) was analyzed 6 times during the experiment and gave a standard deviation of plus or minus 5.5 percent. This variation is illustrated in Figure 9 by the bars above and below the calculated percentages.

The results of the experiment indicate that if the sample is analyzed within 30 minutes of sample collection, the resulting value will be within the repeatability of the procedure. If the sample is allowed to stand more than one hour before analysis, significant sample loss can occur. Because of the possibility of significant sample loss, sample bags were analyzed for 1,3-butadiene as soon after collection as possible.

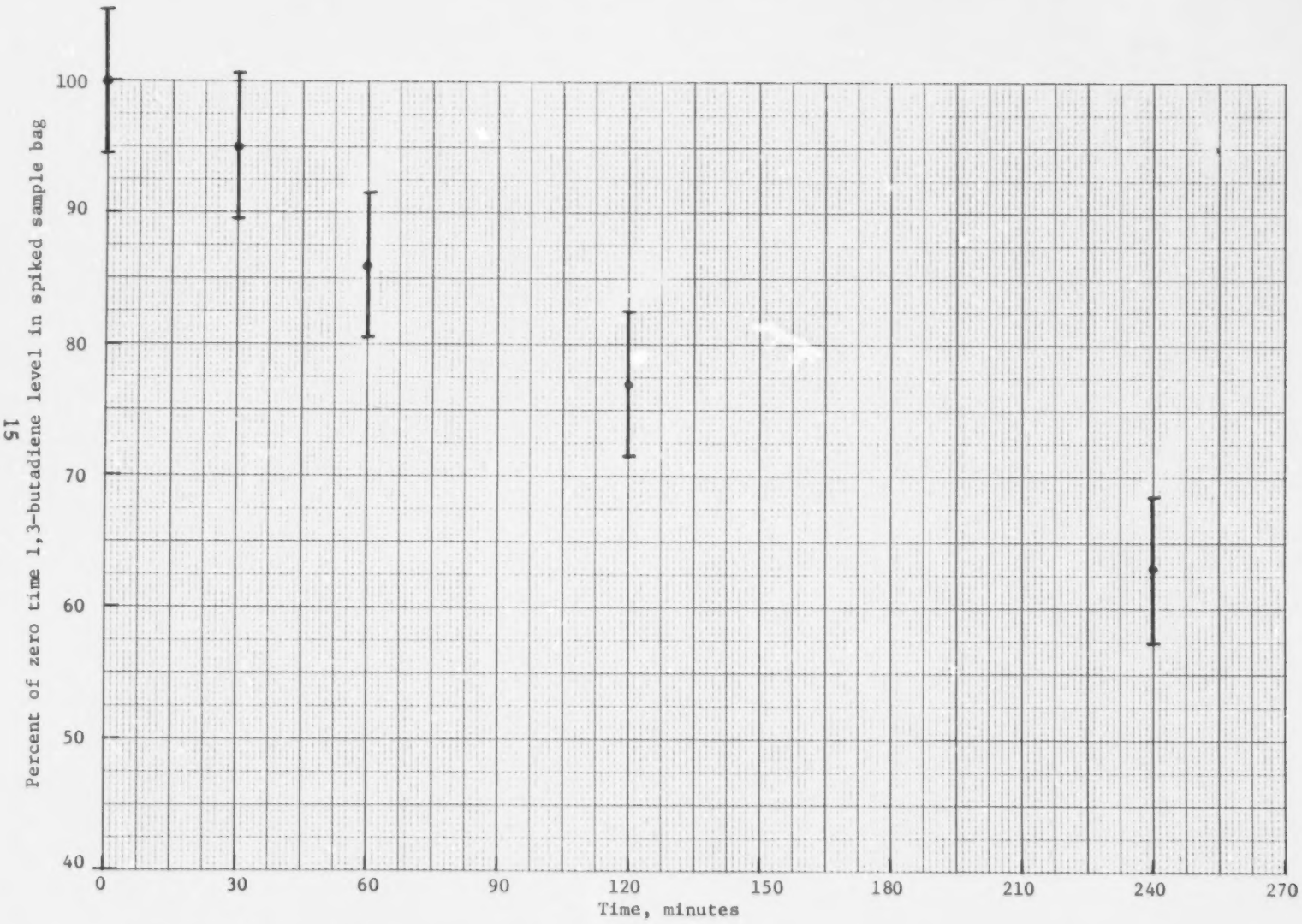

FIGURE 9. DECAY OF 1,3-BUTADIENE IN A DILUTE EXHAUST SAMPLE BAG (COLD-START 505 SAMPLE BAG FROM FTP TESTING OF 1986 CHEVROLET CELEBRITY) SPIKED WITH 1,3-BUTADIENE

IV. RESULTS

This section describes the results of the regulated and 1,3-butadiene emission tests conducted on two vehicles. In addition to 1,3-butadiene, analyses for six other C_4 hydrocarbons were conducted, including: butane, isobutane, 1-butene, isobutylene, cis-2-butene, and trans-2-butene.

A. Regulated Emissions and Fuel Economy

Duplicate FTP tests were conducted on each of the two test vehicles. A summary of the individual and average regulated emission and fuel economy results is presented in Table 4 along with the Federal Emission Standards. Computer printouts for the regulated emissions and fuel economy are included in Appendix B.

TABLE 4. REGULATED EMISSIONS AND FUEL ECONOMY TEST RESULTS

	FTP Emissions, g/mi, except as noted						
	Camaro			Taurus			
	Test 1	Test 2	Avg	Test 1	Test 2	Avg	Federal Standard
Hydrocarbons	0.28	0.28	0.28	0.25	0.25	0.25	0.41
Carbon Monoxide	3.88	5.16	4.52	2.91	2.95	2.93	3.4
Oxides of Nitrogen	0.34	0.43	0.39	0.44	0.44	0.44	1.0
Fuel Economy, mi/gal	23.72	22.91	23.32	23.69	23.14	23.42	

With the exception of one voided test on the Taurus, the operation of the test vehicles was consistent during testing. During the voided test, the Ford Taurus died repeatedly in the initial stages of the hot-start portion of the FTP (Bag 3). Because of these problems, the results of this test (Test 2, Run 1, 1/25/88) were not included in Table 4. Regulated emissions and fuel economy were recorded for the test (HC, 0.38 g/mi; CO. 3.36 g/mi; NO_x, 0.38 g/mi, and fuel economy, 22.72 mi/gal), and a copy of the computer printout for the regulated emissions has been included in Appendix C. The C_4 emissions were also recorded for this test and will be discussed in the following section. One additional test was also conducted on the Camaro (Test 1, Run 1, 1/19/88), however, problems with the 1,3-butadiene analysis system prevented the sampling of a complete set of C_4 data. The Bag 1, 1,3-butadiene emissions were recorded and the results will be included in the following section. The regulated emissions for the entire test were recorded (HC, 0.30 g/mi; CO, 5.48 g/mi; NO_x, 0.35 g/mi; and fuel economy, 23.67 mi/gal) with a copy of the computer printout included in Appendix C. These data were not included in Table 4 since comparable 1,3-butadiene data were not available.

B. 1,3-Butadiene Test Results

Emission measurements for 1,3-butadiene were conducted in duplicate for each of the test vehicles operated over the FTP cycle. The results of these measurements are reported in Table 5. The Camaro (port fuel injection) had higher 1,3-butadiene emission rates than the Taurus (throttle body injection), 1.7 mg/mi

versus 0.9 mg/mi. The 1,3-butadiene for the Camaro also accounted for a higher percentage of the total hydrocarbons than the Taurus, 0.61 percent versus 0.36 percent. The average total mass of 1,3-butadiene generated during the FTP test (unweighted) was 29.93 mg for the Camaro and 15.80 mg for the Taurus. The voided test on the Taurus gave a slightly higher 1,3-butadiene emission rate than the two tests listed in Table 5 (1.5 mg/mi versus 0.8 and 1.0 mg/mi), however, the 1,3-butadiene percentage of the total hydrocarbons was similar to the other tests (0.40 percent versus 0.32 and 0.40 percent).

TABLE 5. 1,3-BUTADIENE EMISSION RESULTS

	FTP Emissions, mg/mi, except as noted					
	Camaro			Taurus		
	Test 1	Test 2	Avg	Test 1	Test 2	Avg
Total Hydrocarbons	280	280	280	250	250	250
1,3-Butadiene	1.8	1.6	1.7	0.8	1.0	0.9
1,3-Butadiene Percent of Total Hydrocarbons	0.64	0.57	0.61	0.32	0.40	0.36
Total mg 1,3-Butadiene per test (not weighted)	31.65	28.20	29.93	14.13	17.46	15.80

The 1,3-butadiene emission results for each FTP segment are given in Table 6 for the two test vehicles. As can be seen in the table, virtually all (> 98%) of the 1,3-butadiene is generated in Bag 1, the first 505-second segment of the cold-start UDDS cycle. The 1,3-butadiene accounted for 0.70 percent of the Bag 1 Taurus emissions and 0.95 percent of the Bag 1 Camaro emissions. The 1,3-butadiene emission rate for Bag 1 of the incomplete Camaro test was 8.6 mg/mi and the percentage of the total hydrocarbons was 1.1 percent. The voided Taurus test (hot-start problems) had lower Bag 1 1,3-butadiene emissions than the recorded tests (3.3 mg/mi versus 4.0 and 4.9 mg/mi), however, the Bag 3 emissions were significant, 2.8 mg/mi, and accounted for 0.35 percent of the total hydrocarbons.

C. C_4 Emission Results

In addition to 1,3-butadiene, the emission rates of six other C_4 hydrocarbons were determined in this program. The emission rates for these six C_4 hydrocarbons (butane, isobutane, 1-butene, isobutylene, cis-2-butene, and trans-2-butene) are listed in Table 7 along with 1,3-butadiene and total hydrocarbon emission rates. Figure 10 illustrates the separation of the C_4 hydrocarbons obtained during the gas chromatography analysis. In general, the Camaro had higher emission rates than the Taurus for the unsaturated C_4 hydrocarbons (1,3-butadiene, 1-butene, isobutylene, and trans-2-butene) while the reverse was noted for the saturated C_4 hydrocarbons (butane, isobutane). 1,3-Butadiene was found to be 13.1 percent of the "butane plus 1,3-butadiene" emissions for the Camaro, and 4.6 percent for the Taurus.

TABLE 6. 1,3-BUTADIENE EMISSION RESULTS FOR EACH FTP SEGMENT

	Camaro Emissions, mg/mi, except as noted								
	Bag 1			Bag 2			Bag 3		
	Test 1	Test 2	Avg	Test 1	Test 2	Avg	Test 1	Test 2	Avg
Total Hydrocarbons	920	830	875	60	90	75	230	240	235
1,3-Butadiene	8.7	7.9	8.3	ND[a]	ND	ND	T[b]	ND	T
1,3-Butadiene (detection limit)	--	--	0.4[c]	--	--	0.6[c]	--	--	0.4
Total mg 1,3-Butadiene per test	31.2	28.2	29.7	ND	ND	ND	0.4	ND	0.4
1,3-Butadiene Percent of Total Hydrocarbons	0.95	0.95	0.95	0	0	0	0.04	0	0.04

	Taurus Emissions, mg/mi, except as noted								
	Bag 1			Bag 2			Bag 3		
	Test 1	Test 2	Avg	Test 1	Test 2	Avg	Test 1	Test 2	Avg
Total Hydrocarbons	660	620	640	80	100	90	250	270	260
1,3-Butadiene	4.0	4.9	4.5	ND	ND	ND	ND	ND	ND
1,3-Butadiene (detection limit)	--	--	0.4	--	--	0.6	--	--	0.4
Total mg 1,3-Butadiene per test	14.1	17.5	15.8	ND	ND	ND	ND	ND	ND
1,3-Butadiene Percent of Total Hydrocarbons	0.61	0.79	0.70	0	0	0	0	0	0

[a]None Detected

[b]Trace, detected but below the level of quantification. Estimated to be in the order of 0.1 mg/mile.

[c]Detection limits for bags 1 and 2 are not equivalent due to differences in CVS volumes and miles driven for the two FTP segments.

TABLE 7. C_4 EMISSION RESULTS

	FTP Emissions, mg/mi, except as noted					
	Camaro			Taurus		
	Test 1	Test 2	Avg	Test 1	Test 2	Avg
Total Hydrocarbons	280	280	280	250	250	250
1,3-Butadiene	1.8	1.6	1.7	0.8	1.0	0.9
Butane	11.0	11.6	11.3	19.8	17.5	18.7
Isobutane	2.1	2.0	2.1	3.9	3.0	3.5
1-Butene	1.9	1.9	1.9	1.6	1.3	1.5
Isobutylene	3.4	3.7	3.6	2.5	2.4	2.5
cis-2-Butene	1.0	1.1	1.1	1.1	1.1	1.1
trans-2-Butene	1.4	1.4	1.4	1.3	1.2	1.3
1,3-Butadiene Percent of Butane plus 1,3-Butadiene	14.1	12.1	13.1	3.9	5.4	4.6

Camaro Bag 1 Sample

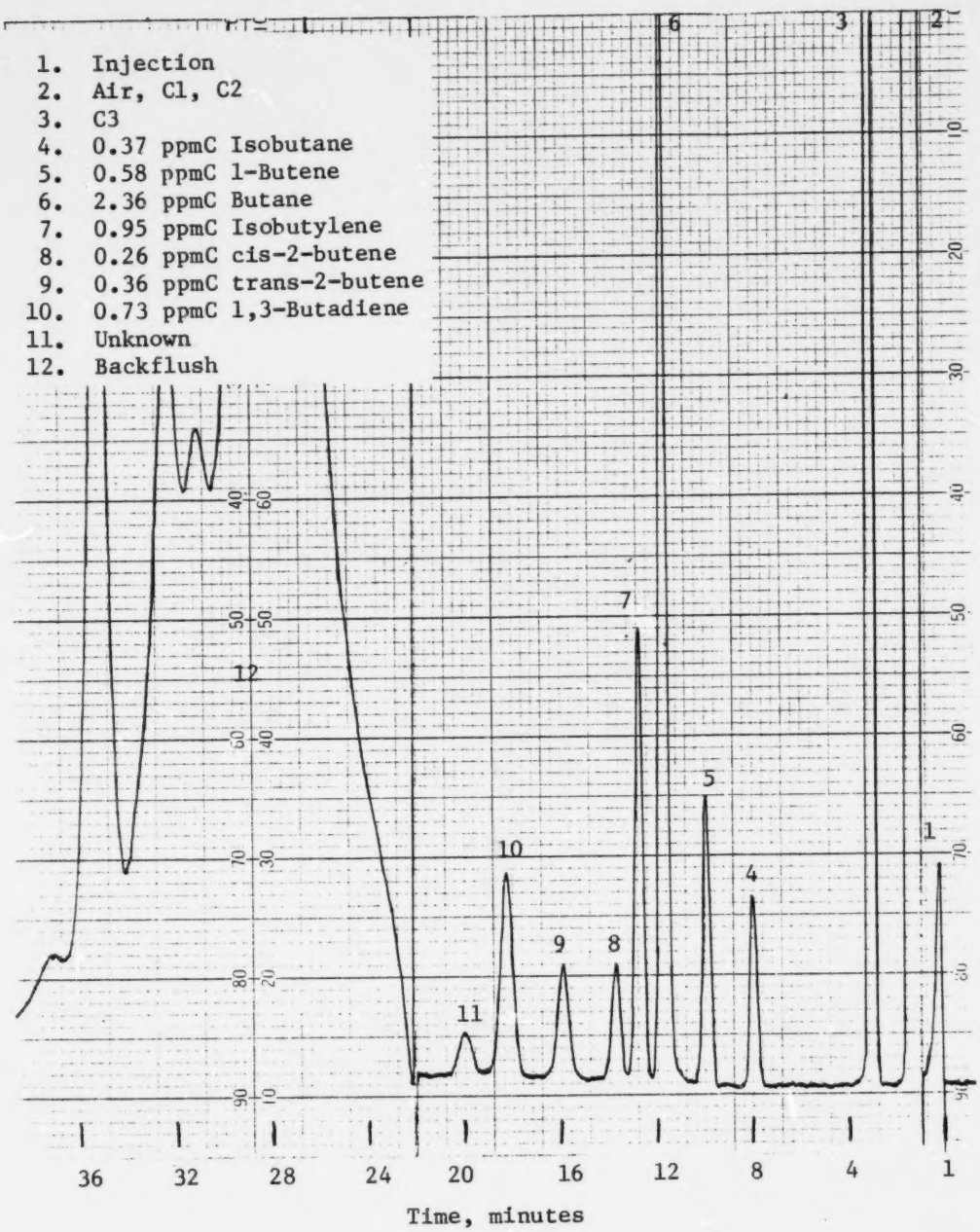

FIGURE 10. SEPARATION OF C_4 HYDROCARBONS

V. QUALITY ASSURANCE

The Quality Assurance (QA) guidelines addressed in the QA plan for this Work Assignment were followed in performing the work for the program. Chassis dynamometer, CVS, and bag cart calibrations were performed using procedures and equipment specified in the Federal Register, and are available for inspection. Quality assurance associated with 1,3-butadiene analyses is described in the following paragraphs.

Tedlar sample bags routinely used with the CVS to collect diluted vehicle exhaust gas for analyses of HC, CO, and NO_x regulated emissions were also employed for 1,3-butadiene analyses utilizing an FID-equipped gas chromatograph. All sample bags were analyzed within one hour of collection to avoid long-term degradation of 1,3-butadiene experienced in the validation experiments. Sample Bag 1 was typically analyzed within 5 minutes of collection, while sample bags 2 and 3 were analyzed within 30 and 60 minutes of collection, respectively. One background bag, background bag 2, was run during the analyses. This background bag was run after all sample bags had been analyzed and within 2 hours of collection. After all sample and background bags had been analyzed, Bag 1 was spiked with the standard sample (containing both butane and 1,3-butadiene) to confirm the presence of 1,3-butadiene in the diluted exhaust.

A series of six consecutive injections of the standard containing 1,3-butadiene and butane during the analysis phase of the program gave average peak areas and standard deviations of 17,180 $\pm$ 313 for 1,3-butadiene and 77,339 $\pm$ 463 for butane. The precision of these injections as percent standard deviation was 1.8 percent for 1,3-butadiene and 0.6 percent for butane. A more reasonable assessment of the precision of the analytical method may be determined by using peak areas from standards actually used to bracket samples run. The precision determination using the results for the 20 standard injections carried out during this program to bracket samples is shown below:

Hydrocarbon Standard	Number of Analyses	Average Area	Standard Deviation in Area	Percent Deviation
1,3-butadiene	20	18,277	795	4.4
Butane	20	78,513	3,530	4.5

Precision determinations by repetitive injections of actual samples were not practical due to the decay of 1,3-butadiene with time.

The program objectives for precision (5.0 percent), accuracy (5.4 percent), and completeness (95 percent) for the analysis of 1,3-butadiene were met with a precision of 4.4 percent, accuracy of 4.8 percent, and completeness of 100 percent. Accuracy was determined employing a certified standard of 1,3-butadiene purchased from Scott Specialty Gases. The analytical accuracy of the purchased gas was $\pm$2 percent as determined by Scott.

The detection limit of 0.03 ppmC for 1,3-butadiene, as used in this report, is the level above which the Hewlett-Packard Model 3353 gas chromatograph computer system can consistently detect and integrate the 1,3-butadiene signal from the GC-FID. Levels between 0.01 and 0.03 ppmC can be detected by the GC-FID, however, quantification by the computer system is variable. These levels have been referred to as trace amounts in this report.

REFERENCES

1. Code of Federal Regulations, Title 40, Chapter 1, Part 85, Subpart H, Sections applicable to Light-Duty Vehicles.

2. (a) F.M. Black and R.L. Bradow, "Patterns of Hydrocarbon Emissions from 1975 Production Cars." SAE 750681 presented at Fuels and Lubricants Meeting, Houston, Texas, June 1975.
(b) F.M. Black, "The Impact of Emission Control Technology on Passenger Car Hydrocarbon Emission Rates and Patterns." Proceedings of the International Conference on Photochemical Oxidant Pollution and Its Control, EPA-600/3-77-001b, January 1977.
(c) F.M. Black and L.E. High, "Automotive Hydrocarbon Emission Patterns and the Measurement of Nonmethane Emission Rates." SAE 770144 presented at SAE Congress, Detroit, Michigan, February 1977.
(d) F.M. Black and L.E. High, "Methodology for Determining Particulate and Gaseous Diesel Hydrocarbon Emissions." SAE 790422 presented at SAE Congress and Exposition, Detroit, Michigan, February 1979.
(e) J.E. Sigsby, S. Tejada, et al. "Volatile Organic Compound Emissions from 46 In-Use Passenger Cars." Environmental Science and Technology, Vol. 21, p. 466, May 1987.

APPENDIX A

1,3-BUTADIENE PROCEDURE

MEASUREMENT OF 1,3-BUTADIENE IN EXHAUST

This procedure was developed to measure 1,3-butadiene in dilute vehicle exhaust. In addition to 1,3-butadiene, the procedure provides separation and relative exhaust concentrations for six other C_4 hydrocarbons including: isobutane, butane, 1-butene, isobutylene, cis-2-butene, and trans-2-butene. Standard CVS bag samples are analyzed for 1,3-butadiene using a gas chromatograph equipped with a flame ionization detector (FID). External 1,3-butadiene standards in zero air are used to quantify the results. Detection limits for this procedure are on the order of 0.03 ppmC in dilute exhaust for 1,3-butadiene.

Analytical Procedure

The analysis of 1,3-butadiene is accomplished by collecting 1,3-butadiene in Tedlar bags and analyzing the samples with a gas chromatograph equipped with a flame ionization detector (FID). The analysis flow schematic for 1,3-butadiene is shown in Figure A-1. A detailed description of the procedure follows.

The gas chromatograph system for the analysis of 1,3-butadiene utilizes a Perkin-Elmer Model 3920B gas chromatograph with an FID, two pneumatically-operated and electrically-controlled Seiscor valves, and an analytical column. The analytical column is a 9' x 1/8" stainless steel column containing 80/100 Carbopack C with 0.19% picric acid. The carrier gas is helium, which flows through the column at a rate of 27 ml/min. The column temperature is maintained at 40°C for analysis. A chromatogram of a 2.0 ppmC 1,3-butadiene and 8.04 ppmC butane standard is shown in Figure A-2. A chromatogram of an exhaust sample is shown in Figure A-3. To quantify the results, the sample peak areas are compared to the peak area of a standard, which was run before and after each set of sample bags. Figure A-4 shows the analytical system with gas chromatograph, detector, sample injection system, and recorder.

The analytical column, sampling loop, and Seiscor valves are all housed in the GC oven and are operated with the aid of a specially fabricated control system. Figure A-5 (Step 1) illustrates the gas chromatograph flow schematic with the gas sampling valve in the purge position and the backflush valve in the foreflush position for the analytical column. Figure A-6 (Step 2) illustrates the flow schematic when the gas sampling valve is actuated and the backflushed valve is still in the foreflush position. Once the 1,3-butadiene peak has eluted, the backflush valve is activated and the C_5 and heavier molecular weight hydrocarbons are backflushed from the analytical column (Figure A-7). Under normal conditions, it is not necessary to backflush the calibration standards since they are free of contaminants that would interfere with the analytical column.

Control System

The control of the two Seiscor valves is accomplished by ATC timers and ASCO electric solenoid valves. The electric schematic for the control of the Seiscor valves using these timers and electric solenoid valves is shown in Figure A-8. The flow schematics for vacuum and pressure lines to the Seiscor valves are presented in Figures A-9, A-10, and A-11.

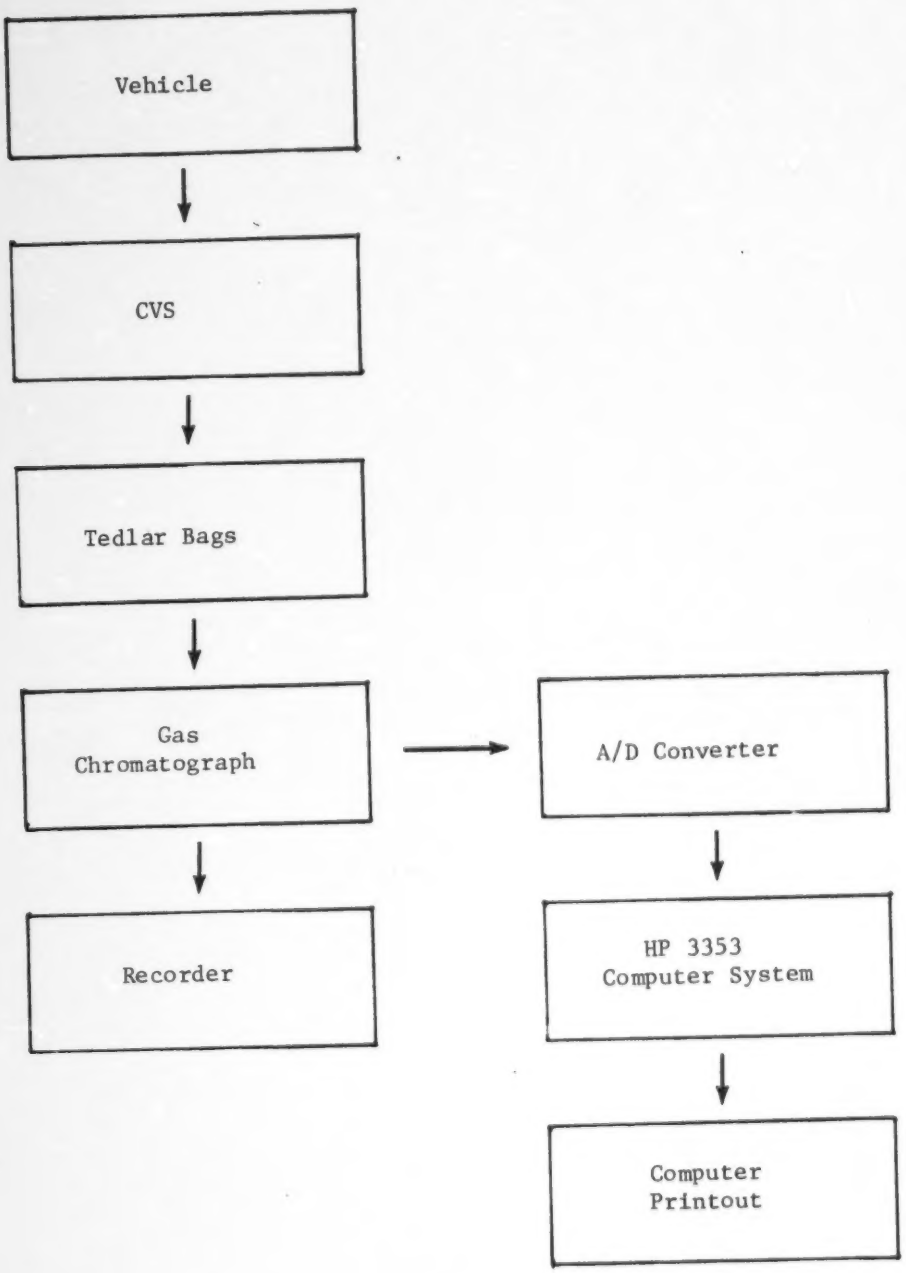

FIGURE A-1. THE ANALYSIS FLOW SCHEMATIC FOR 1,3-BUTADIENE

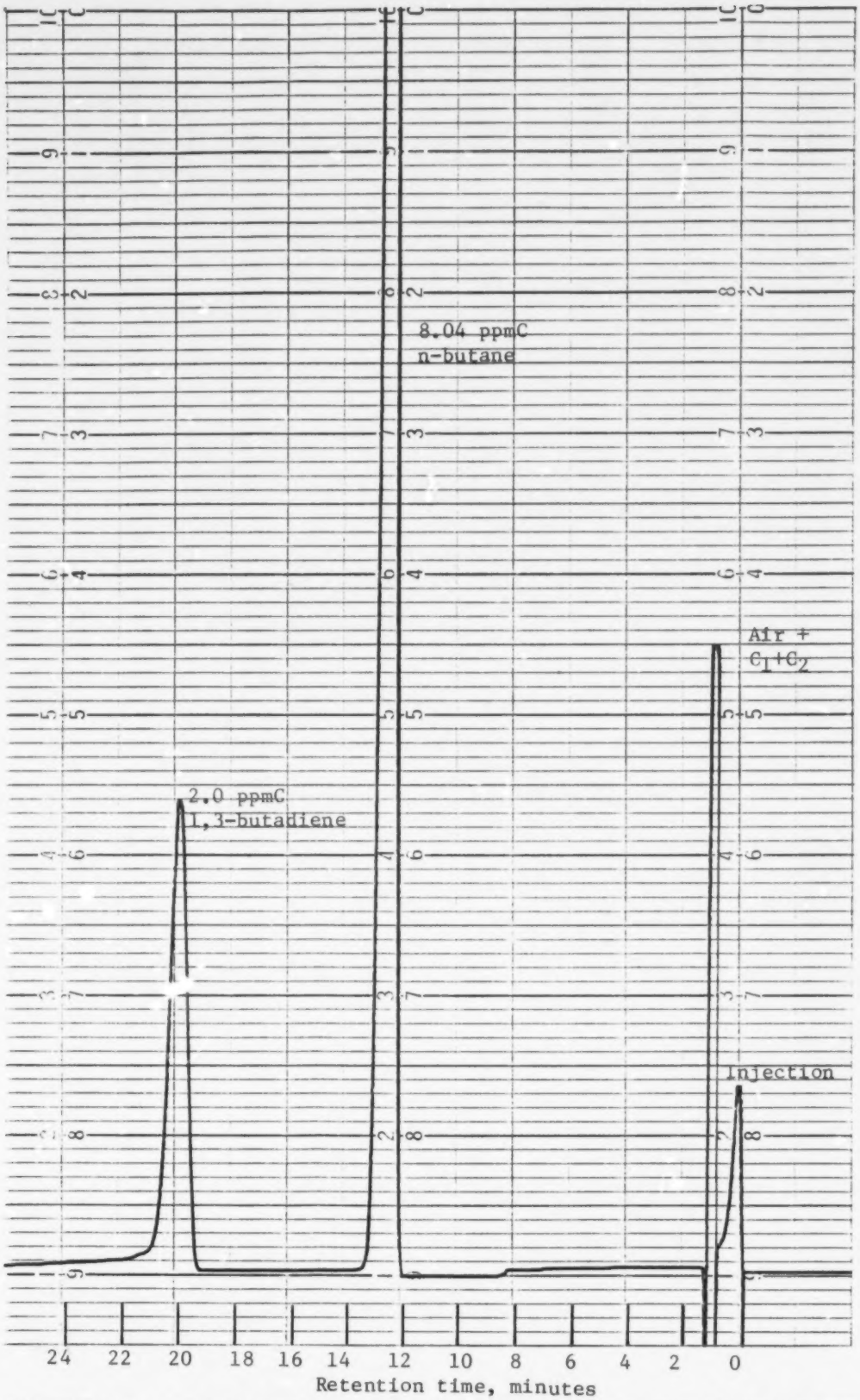

FIGURE A-2. CHROMATOGRAM OF 1,3-BUTADIENE AND N-BUTANE STANDARD

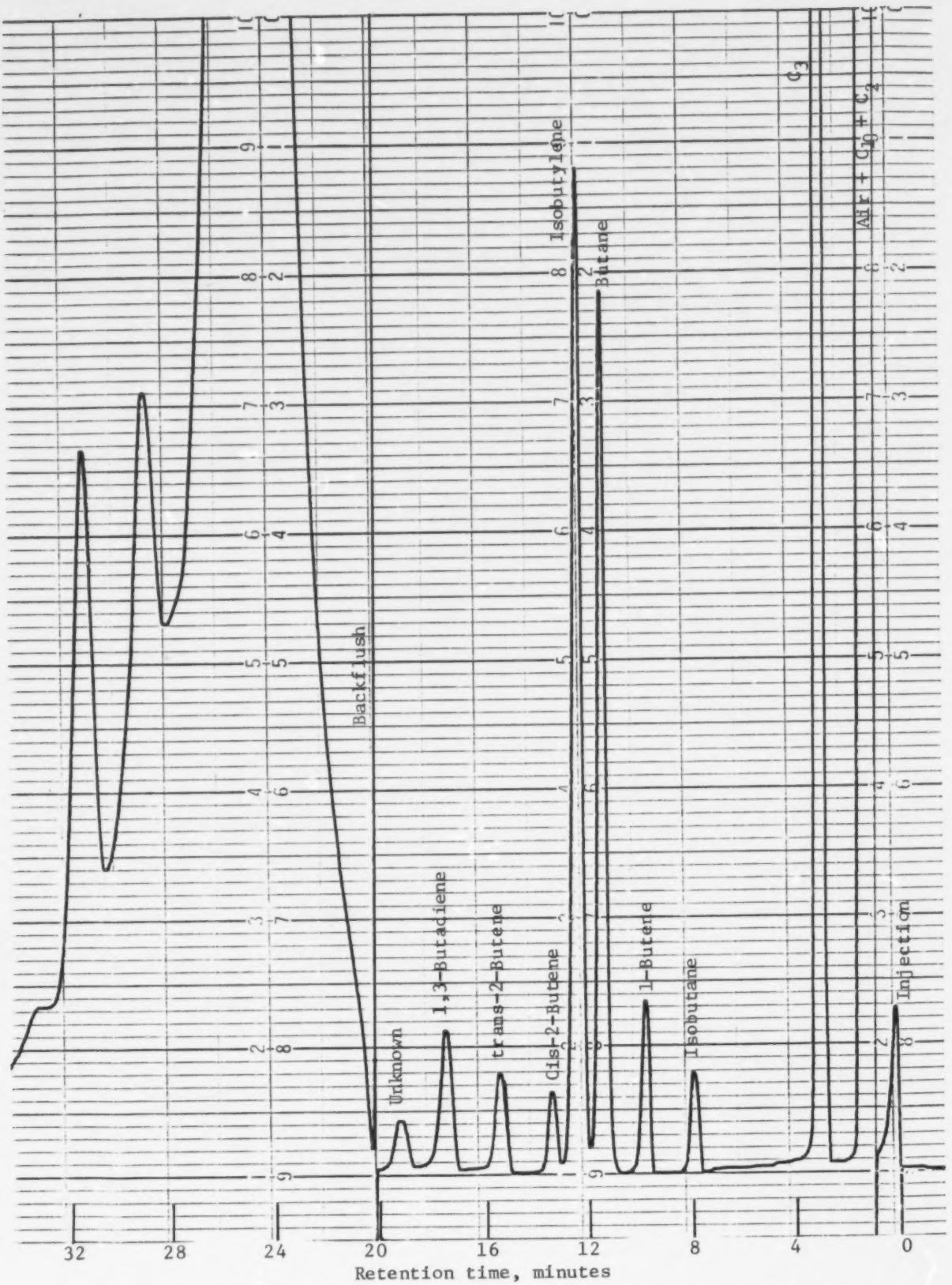

FIGURE A-3. CHROMATOGRAM OF DILUTE EXHAUST SAMPLES

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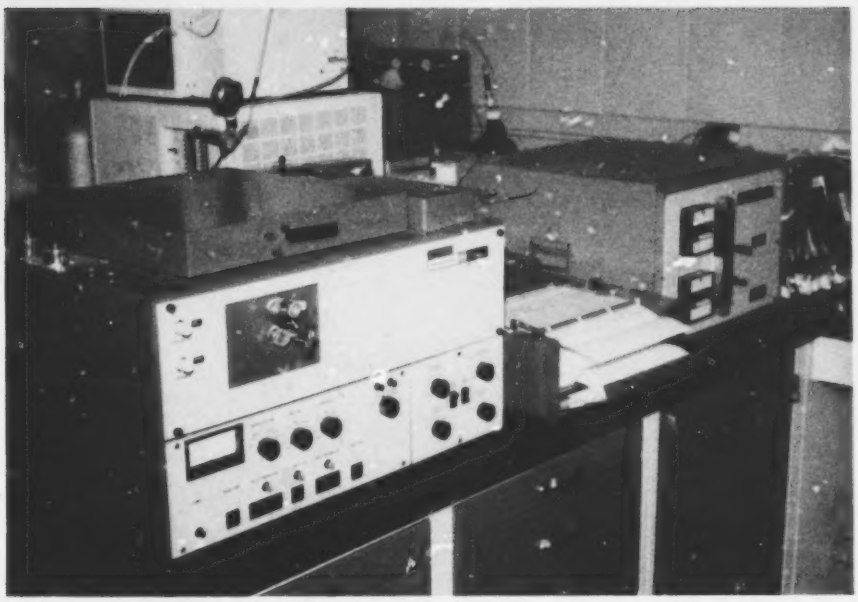

FIGURE A-4. ANALYTICAL SYSTEM

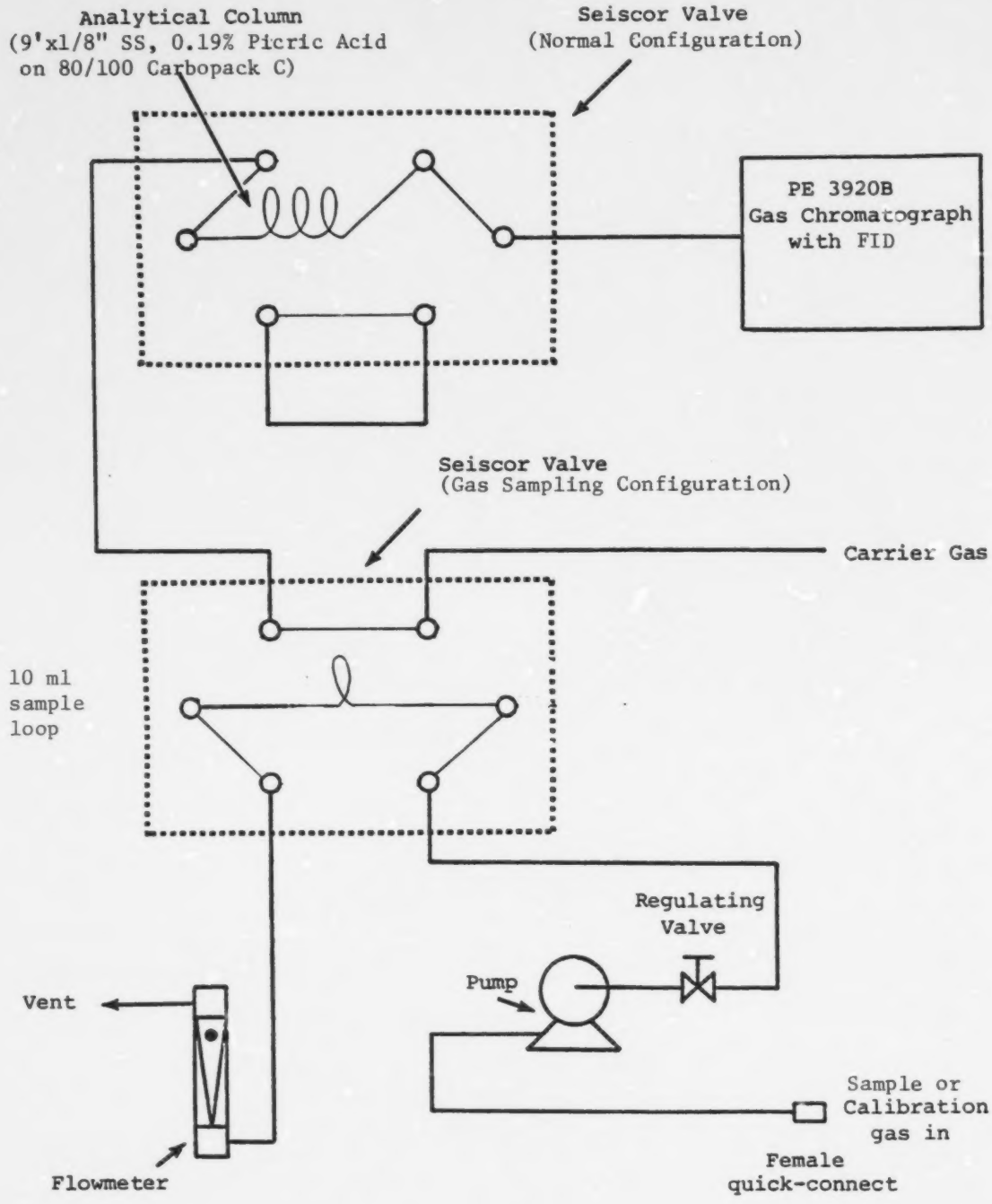

FIGURE A-5. FLOW SCHEMATIC OF 1,3-BUTADIENE ANALYTICAL SYSTEM (STEP 1 - PURGE OF SAMPLE LOOP)

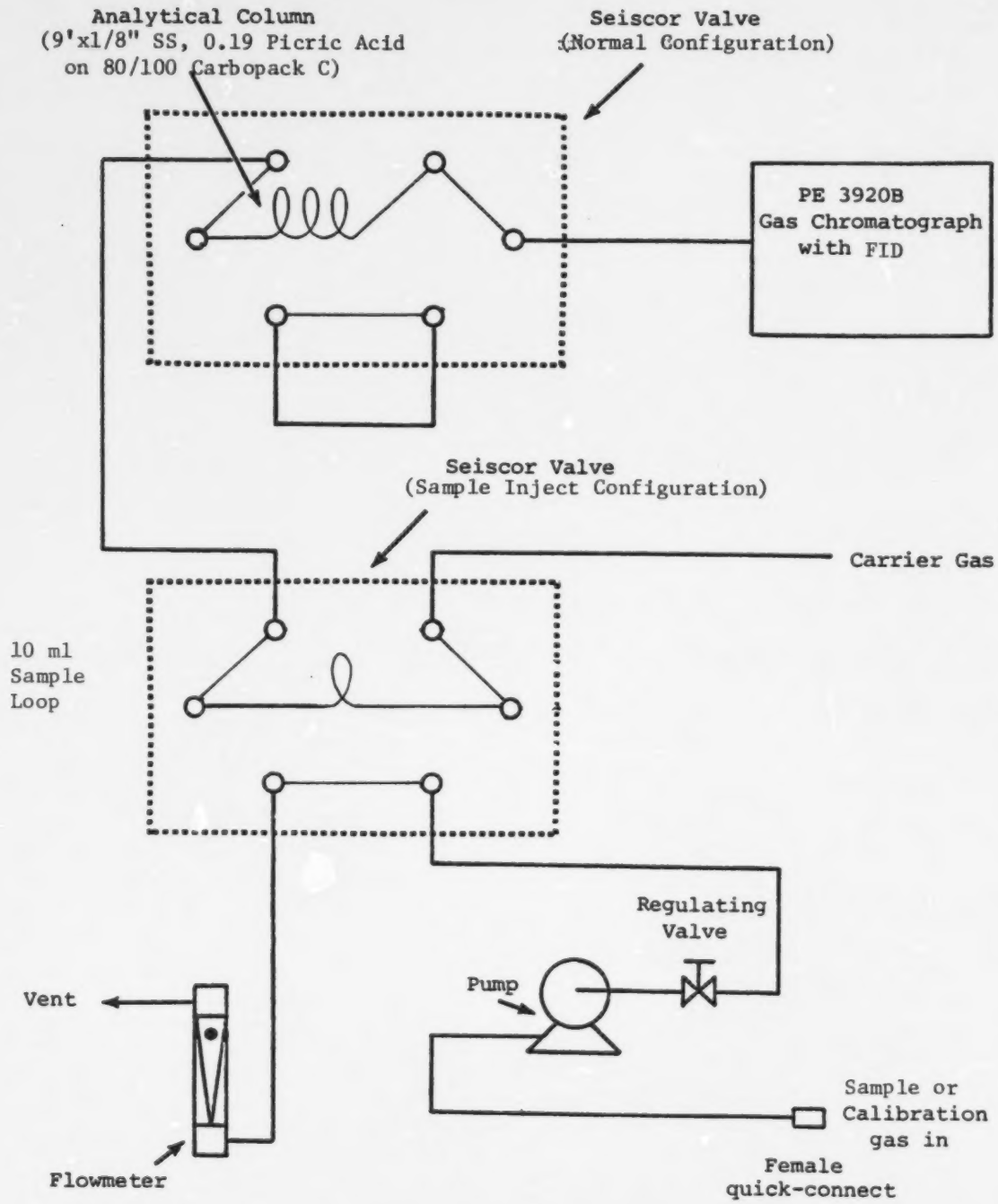

FIGURE A-6. FLOW SCHEMATIC OF 1,3-BUTADIENE ANALYTICAL SYSTEM (STEP 2 - INJECT SAMPLE OR CALIBRATION GAS INTO SYSTEM)

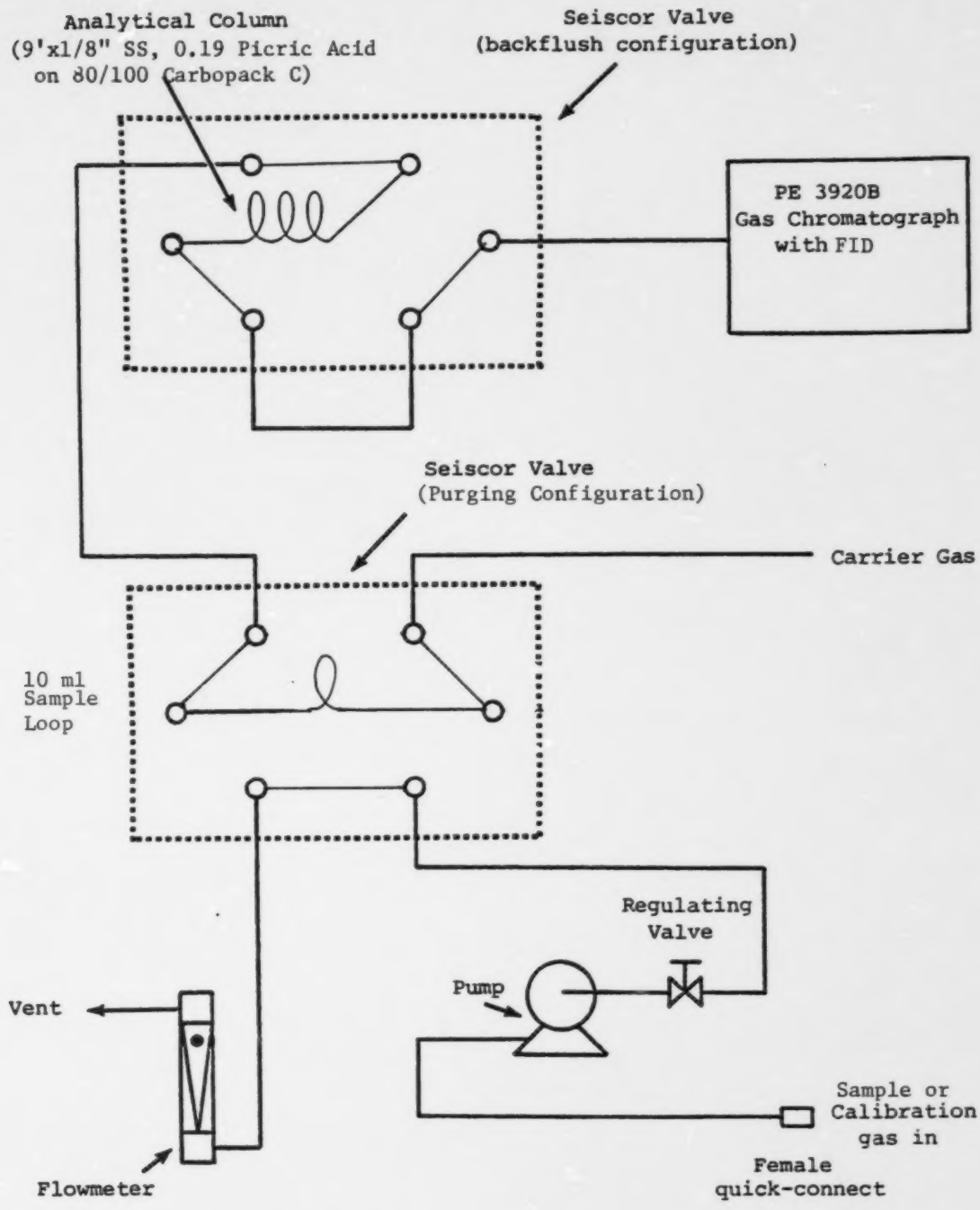

FIGURE A-7. FLOW SCHEMATIC OF 1,3-BUTADIENE ANALYSIS SYSTEM (STEP 3 - BACKFLUSH ANALYTICAL COLUMN)

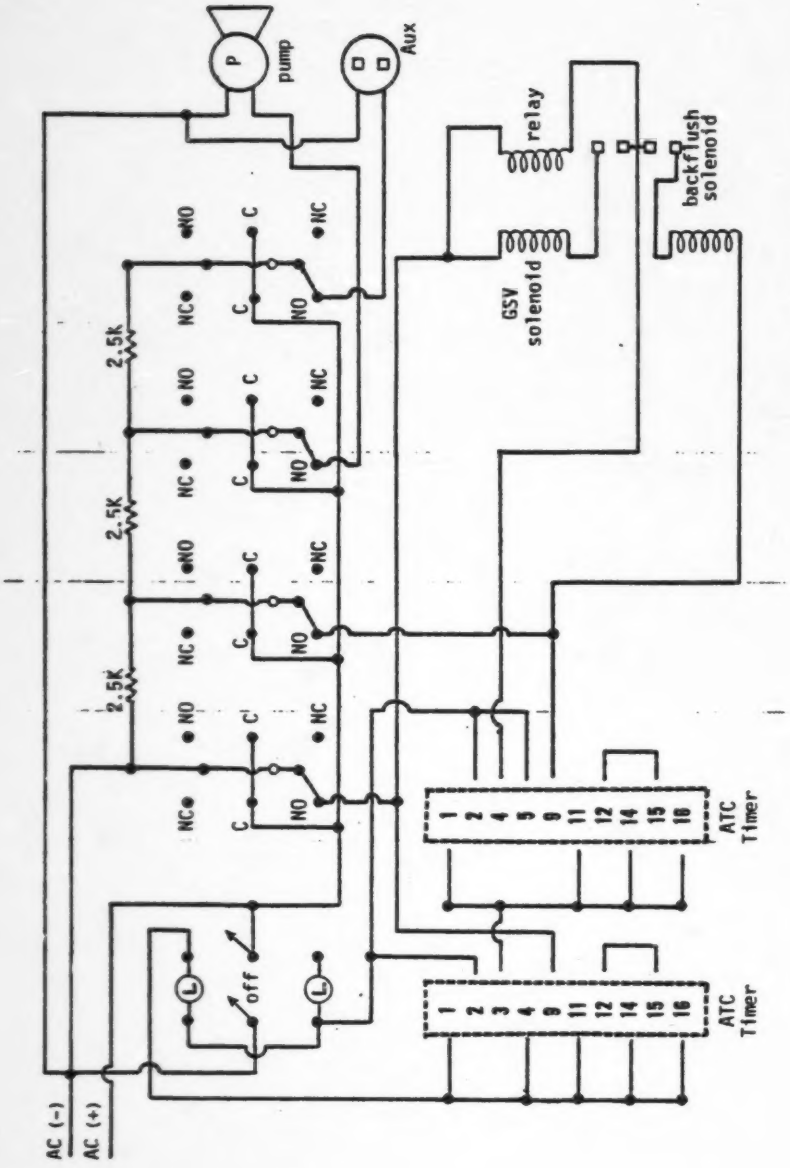

FIGURE A-8. ELECTRICAL SCHEMATIC OF 1,3-BUTADIENE ANALYSIS SYSTEM

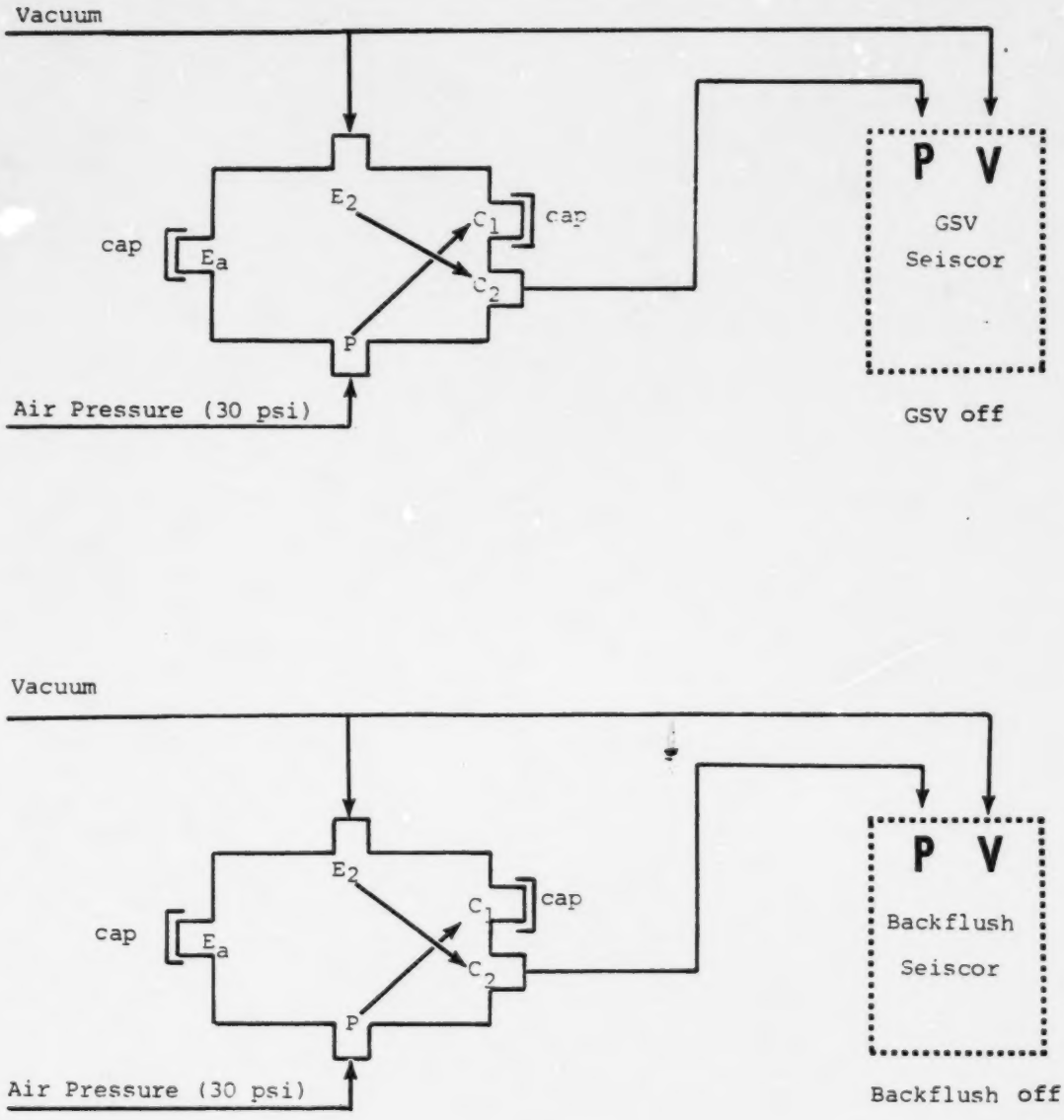

FIGURE A-9. FLOW SCHEMATIC IN ELECTRIC SOLENOID VALVES (BOTH VALVES DE-ENERGIZED)

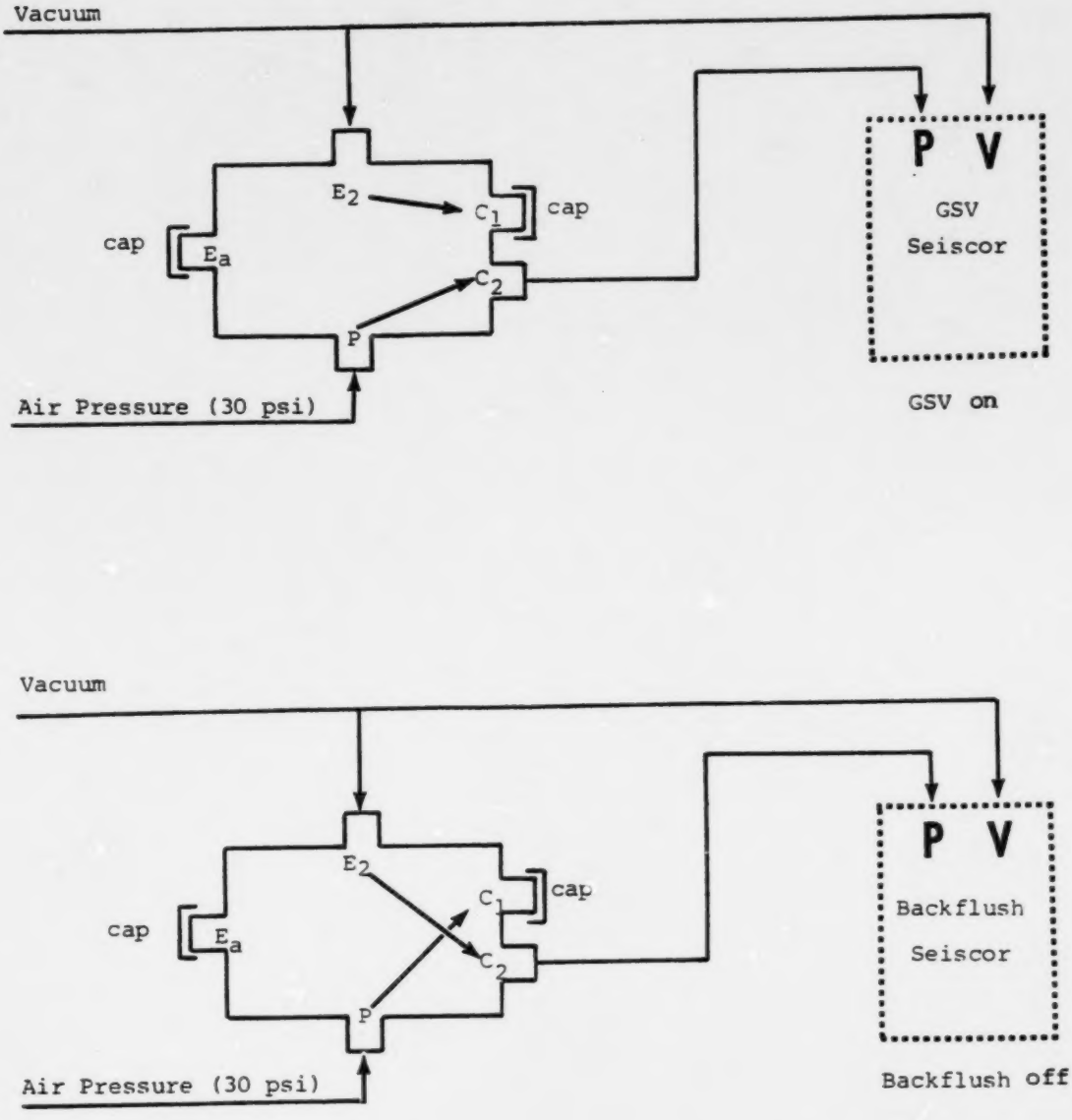

FIGURE A-10. FLOW SCHEMATIC IN ELECTRIC SOLENOID VALVES (GSV ENERGIZED, BACKFLUSH DE-ENERGIZED)

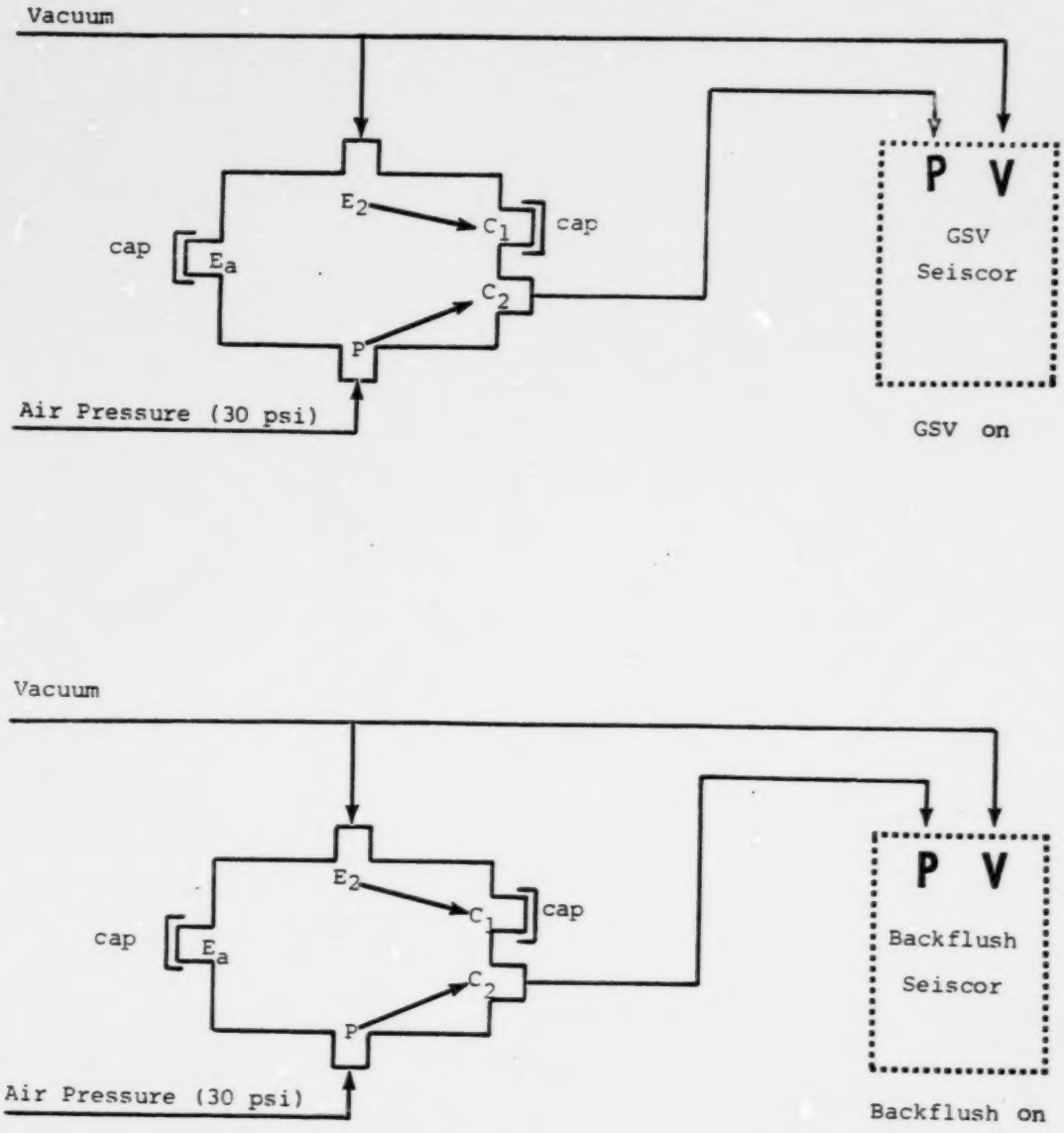

FIGURE A-11. FLOW SCHEMATIC IN ELECTRIC SOLENOID VALVES (BOTH VALVES ENERGIZED)

Sample Calculations

The quantification of 1,3-butadiene is based on a direct comparison of the 1,3-butadiene in exhaust with a calibration blend of a known 1,3-butadiene concentration. Two basic assumptions are made in the calculations that should be considered when conducting 1,3-butadiene analyses. The first assumption is that the exhaust samples are analyzed as quickly as possible after collection and that the measurements are made within the working range of the system. Exhaust samples spiked with 1,3-butadiene have indicated a loss of 1,3-butadiene with time. Calculations for this system are based on the assumption that the analyses are conducted within one hour of sample collection and minimal sample decay has occurred. The use of a gas divider and a 2.0 ppmC 1,3-butadiene standard has shown that the FID response of 1,3-butadiene is linear in the 0.05 to 2.0 ppmC range. Procedural development work has found that 1,3-butadiene levels are generally below 2.0 ppmC in dilute exhaust. The other C_4 hydrocarbons are quantified by direct comparisons of the hydrocarbons in exhaust with a calibration blend of butane. If the above assumptions are followed, then the following relationships are valid.

Let C_{sam} = ppmC concentration of 1,3-butadiene in sample
C_{std} = ppmC concentration of 1,3-butadiene in standard
A_{sam} = area of 1,3-butadiene peak in sample
A_{std} = area of 1,3-butadiene peak in standard

$$\frac{A_{std}}{C_{std}} = \frac{A_{sam}}{C_{sam}}$$

Solving for C_{sam}

$$C_{sam} = \frac{A_{sam}}{A_{std}} \times C_{std}$$

If a 2.0 ppmC 1,3-butadiene (in air) calibration blend gives 8000 area counts for the 1,3-butadiene peak and an exhaust sample gives 1000 area counts for the 1,3-butadiene peak, then the 1,3-butadiene in the exhaust is calculated as follows:

$$C_{sam} = \frac{A_{sam} \times C_{std}}{A_{std}}$$

$$C_{sam} = \frac{1{,}000 \times 2.0}{8{,}000}$$

$$C_{sam} = 0.25 \text{ ppmC}$$

The 1,3-butadiene concentration in ppmC can be multiplied by the per carbon density of 1,3-butadiene at 68°F and 29.92" Hg (562 μg/ml) to give a mass per unit volume of 1,3-butadiene in dilute exhaust ($\mu g/m^3$) for subsequent mass calculations.

Equipment

The analyses for 1,3-butadiene are performed using a gas chromatograph equipped with a flame ionization detector. The detector, electrometer, recorder,

and GC integrator are the major electronic components in the detection system. A control console was fabricated to house the mechanical hardware items that are necessary for the proper operation of the 1,3-butadiene analysis system. Major items in the analysis system are listed below:

Gas Chromatograph

1. Perkin-Elmer Model 3920 gas chromatograph equipped with flame ionization detector
2. Soltec Model B-281 1 mv recorder
3. Hewlett-Packard Model 3353 gas chromatograph computer system with remote printer
4. Hewlett-Packard Model 1865A A/D Converter
5. Analytical column, 9' x 1/8" SS, 0.19 picric on 80/100 mesh Graphpac GC
6. Seiscor valve - gas sampling configuration
7. Seiscor valve - backflush configuration

Control Console System

1. ATC timers, Model 325A346A10PX (2 ea)
2. ASCO solenoid valve, Model 834501 (2 ea)
3. Brook flowmeter, R-2-15-A w/ss float; 0-150 scale
4. Metal Bellows MD-155 pump
5. Female quick-connect, stainless steel
6. Nupro Model 2M stainless steel, copper and Teflon tubing (1/8" and 1/16")
7. Miscellaneous stainless steel and brass unions, tees, etc.
8. Bud Classic II control console cabinet
9. Miscellaneous electrical on-off switches

APPENDIX B

COMPUTER PRINTOUTS OF THE REGULATED EMISSIONS AND FUEL ECONOMY TEST RESULTS

Table B-	Vehicle	Test No.	Run No.
1	Camaro	1	2
2	Camaro	2	1
3	Taurus	1	1
4	Taurus	2	2

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TABLE B-1. FTP - VEHICLE EMISSIONS RESULTS -

PROJECT 08-1567-001

TEST NO. 1 RUN 2
VEHICLE MODEL 86 CAMARO
ENGINE 2.8 L(171. CID) L-6
TRANSMISSION A4

VEHICLE NO.1
DATE 1/20/88
BAG CART NO. 2
DYNO NO. 3
CVS NO. 2

TEST WEIGHT 1586. KG(3500. LBS)
ACTUAL ROAD LOAD 6.3 KW(8.4 HP)
GASOLINE EM-781-F
ODOMETER 53260. KM(33094. MILES)

BAROMETER 746.00 MM HG(29.37 IN HG)
RELATIVE HUMIDITY 16. PCT
DRY BULB TEMP. 23.9 DEG C(75.0 DEG F)
ABS. HUMIDITY 3.0 GM/KG
NOX HUMIDITY CORRECTION FACTOR .80

BAG RESULTS

BAG NUMBER	1	2	3
DESCRIPTION	COLD TRANSIENT	STABILIZED	HOT TRANSIENT
BLOWER DIF P MM. H2O(IN. H2O)	762.0 (30.0)	762.0 (30.0)	762.0 (30.0)
BLOWER INLET P MM. H2O(IN. H2O)	762.0 (30.0)	762.0 (30.0)	762.0 (30.0)
BLOWER INLET TEMP. DEG. C(DEG. F)	45.6 (114.0)	41.1 (106.0)	44.4 (112.0)
BLOWER REVOLUTIONS	40637.	69687.	40572.
TOT FLOW STD. CU. METRES(SCF)	76.1 (2686.)	131.0 (4626.)	75.8 (2677.)
THC SAMPLE METER/RANGE/PPM	79.7/ 2/ 80.	8.2/ 2/ 8.	22.4/ 2/ 23.
THC BCKGRD METER/RANGE/PPM	5.4/ 2/ 6.	5.3/ 2/ 5.	4.5/ 2/ 5.
CO SAMPLE METER/RANGE/PPM	81.1/14/ 386.	37.7/12/ 38.	44.4/14/ 131.
CO BCKGRD METER/RANGE/PPM	.9/14/ 4.	1.7/12/ 2.	.4/14/ 2.
CO2 SAMPLE METER/RANGE/PCT	98.2/14/1.0032	81.3/14/ .6848	89.2/14/ .8487
CO2 BCKGRD METER/RANGE/PCT	14.1/14/ .0502	13.8/14/ .0489	13.3/14/ .0468
NOX SAMPLE METER/RANGE/PPM	98.4/ 1/ 24.5	15.1/ 1/ 3.9	41.2/ 1/ 10.3
NOX BCKGRD METER/RANGE/PPM	1.9/ 1/ .5	1.5/ 1/ .4	.8/ 1/ .2
DILUTION FACTOR	12.77	19.44	15.41
THC CONCENTRATION PPM	75.	3.	18.
CO CONCENTRATION PPM	374.	35.	186.
CO2 CONCENTRATION PCT	.9570	.6385	.8049
NOX CONCENTRATION PPM	24.0	3.5	10.1
THC MASS GRAMS	3.29	.24	.81
CO MASS GRAMS	33.10	5.41	16.40
CO2 MASS GRAMS	1332.9	1531.4	1117.3
NOX MASS GRAMS	2.79	.70	1.17
THC GRAMS/MI	.92	.06	.23
CO GRAMS/MI	9.27	1.39	4.60
CO2 GRAMS/MI	373.2	392.4	313.3
NOX GRAMS/MI	.78	.18	.33
FUEL ECONOMY IN MPG	22.70	22.46	27.60
RUN TIME SECONDS	505.	867.	505.
MEASURED DISTANCE MI	3.57	3.90	3.57
SCF, DRY	.986	.988	.987

COMPOSITE RESULTS

TEST NUMBER 1
BAROMETER MM HG 746.0
HUMIDITY G/KG 3.0
TEMPERATURE DEG C 23.9

		3-BAG	(4-BAG)
CARBON DIOXIDE	G/MI	366.9	(.0)
FUEL ECONOMY	MPG	23.72	(.00)
HYDROCARBONS (THC)	G/MI	.28	(.00)
CARBON MONOXIDE	G/MI	3.88	(.00)
OXIDES OF NITROGEN	G/MI	.34	(.00)

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SOUTHWEST RESEARCH INSTITUTE - DEPARTMENT OF EMISSIONS RESEARCH
TABLE B-2.FTP - VEHICLE EMISSIONS RESULTS -
PROJECT 08-1567-001

TEST NO. 2 RUN 1
VEHICLE MODEL 86 CAMARO
ENGINE 2.8 L(171. CID) L-6
TRANSMISSION A4

VEHICLE NO. 1
DATE 1/21/88
BAG CART NO. 2
DYNO NO. 3
CVS NO. 2

TEST WEIGHT 1588. KG(3500. LBS)
ACTUAL ROAD LOAD 6.3 KW(8.4 HP)
GASOLINE EM-781-F
ODOMETER 53277. KM(33105. MILES)

BAROMETER 747.27 MM HG(29.42 IN HG)
RELATIVE HUMIDITY 18. PCT
DRY BULB TEMP. 25.0 DEG C(77.0 DEG F)
ABS. HUMIDITY 3.6 GM/KG
NOX HUMIDITY CORRECTION FACTOR .81

BAG RESULTS

BAG NUMBER	1	2	3
DESCRIPTION	COLD TRANSIENT	STABILIZED	HOT TRANSIENT
BLOWER DIF P MM. H2O(IN. H2O)	762.0 (30.0)	762.0 (30.0)	762.0 (30.0)
BLOWER INLET P MM. H2O(IN. H2O)	762.0 (30.0)	762.0 (30.0)	762.0 (30.0)
BLOWER INLET TEMP. DEG. C(DEG. F)	43.3 (110.0)	40.6 (105.0)	41.7 (107.0)
BLOWER REVOLUTIONS	40501.	69600.	40442.
TOT FLOW STD. CU. METRES(SCF)	76.0 (2683.)	131.2 (4634.)	76.1 (2687.)
THC SAMPLE METER/RANGE/PPM	72.6/ 2/ 73.	10.1/ 2/ 10.	24.7/ 2/ 25.
THC BCKGRD METER/RANGE/PPM	6.1/ 2/ 6.	6.0/ 2/ 6.	5.5/ 2/ 6.
CO SAMPLE METER/RANGE/PPM	92.7/14/ 457.	67.0/12/ 67.	56.9/14/ 253.
CO BCKGRD METER/RANGE/PPM	2.1/14/ 8.	6.3/12/ 6.	1.2/14/ 5.
CO2 SAMPLE METER/RANGE/PCT	96.3/14/1.0352	82.0/14/ .6979	90.1/14/ .8700
CO2 BCKGRD METER/RANGE/PCT	15.8/14/ .0574	15.4/14/ .0557	15.1/14/ .0544
NOX SAMPLE METER/RANGE/PPM	28.9/ 2/ 29.0	20.2/ 1/ 5.2	44.7/ 1/ 11.2
NOX BCKGRD METER/RANGE/PPM	.6/ 2/ .6	1.2/ 1/ .3	1.7/ 1/ .4
DILUTION FACTOR	12.33	18.99	14.93
THC CONCENTRATION PPM	67.	5.	20.
CO CONCENTRATION PPM	438.	60.	243.
CO2 CONCENTRATION PCT	.9824	.6452	.8192
NOX CONCENTRATION PPM	28.4	4.9	10.8
THC MASS GRAMS	2.94	.34	.87
CO MASS GRAMS	38.72	9.14	21.56
CO2 MASS GRAMS	1366.5	1550.0	1141.2
NOX MASS GRAMS	3.34	.99	1.27
THC GRAMS/MI	.83	.09	.24
CO GRAMS/MI	10.91	2.39	6.08
CO2 GRAMS/MI	385.0	405.0	321.7
NOX GRAMS/MI	.94	.26	.36
FUEL ECONOMY IN MPG	21.91	21.68	26.70
RUN TIME SECONDS	505.	867.	504.
MEASURED DISTANCE MI	3.55	3.83	3.55
SCF, DRY	.985	.988	.986

COMPOSITE RESULTS

TEST NUMBER 2
BAROMETER MM HG 747.3
HUMIDITY G/KG 3.6
TEMPERATURE DEG C 25.0

		3-BAG	(4-BAG)
CARBON DIOXIDE	G/MI	378.1	(.0)
FUEL ECONOMY	MPG	22.91	(.00)
HYDROCARBONS (THC)	G/MI	.28	(.00)
CARBON MONOXIDE	G/MI	5.16	(.00)
OXIDES OF NITROGEN	G/MI	.43	(.00)

SOUTHWEST RESEARCH INSTITUTE - DEPARTMENT OF EMISSIONS RESEARCH
TABLE B-3. FTP - VEHICLE EMISSIONS RESULTS -
PROJECT 08-1567-001

TEST NO. 1 RUN 1	VEHICLE NO.2	TEST WEIGHT 1361. KG(3000. LBS)
VEHICLE MODEL 87 FORD TAURU	DATE 1/22/88	ACTUAL ROAD LOAD 5.5 KW(7.4 HP)
ENGINE 2.5 L(150. CID) L-4	BAG CART NO. 2	GASOLINE EM-781-F
TRANSMISSION A3	DYNO NO. 3	ODOMETER 45997. KM(28581. MILES)
	CVS NO. 2	
BAROMETER 749.05 MM HG(29.49 IN HG)	DRY BULB TEMP. 25.6 DEG C(78.0 DEG F)	
RELATIVE HUMIDITY 14. PCT	ABS. HUMIDITY 2.8 GM/KG	NOX HUMIDITY CORRECTION FACTOR .79

BAG RESULTS

BAG NUMBER	1	2	3
DESCRIPTION	COLD TRANSIENT	STABILIZED	HOT TRANSIENT
BLOWER DIF P MM. H2O(IN. H2O)	762.0 (30.0)	762.0 (30.0)	762.0 (30.0)
BLOWER INLET P MM. H2O(IN. H2O)	762.0 (30.0)	762.0 (30.0)	762.0 (30.0)
BLOWER INLET TEMP. DEG. C(DEG. F)	43.3 (110.0)	42.2 (108.0)	43.3 (110.0)
BLOWER REVOLUTIONS	40611.	69615.	40556.
TOT FLOW STD. CU. METRES(SCF)	76.4 (2697.)	131.2 (4632.)	76.3 (2693.)
THC SAMPLE METER/RANGE/PPM	57.6/ 2/ 58.	9.5/ 2/ 10.	24.5/ 2/ 25.
THC BCKGRD METER/RANGE/PPM	4.9/ 2/ 5.	5.6/ 2/ 6.	5.1/ 2/ 5.
CO SAMPLE METER/RANGE/PPM	75.4/14/ 353.	13.4/12/ 14.	56.6/13/ 134.
CO BCKGRD METER/RANGE/PPM	.8/14/ 3.	1.9/12/ 2.	.6/13/ 2.
CO2 SAMPLE METER/RANGE/PCT	95.3/14/1.0061	79.5/14/ .6523	90.6/14/ .8821
CO2 BCKGRD METER/RANGE/PCT	12.7/14/ .0444	12.7/14/ .0444	12.7/14/ .0444
NOX SAMPLE METER/RANGE/PPM	79.8/ 1/ 20.0	24.3/ 1/ 6.2	65.2/ 1/ 16.3
NOX BCKGRD METER/RANGE/PPM	.9/ 1/ .2	.5/ 1/ .1	.3/ 1/ .0
DILUTION FACTOR	12.81	20.47	14.93
THC CONCENTRATION PPM	53.	4.	20.
CO CONCENTRATION PPM	342.	12.	130.
CO2 CONCENTRATION PCT	.9651	.6101	.8406
NOX CONCENTRATION PPM	19.8	6.0	16.3
THC MASS GRAMS	2.35	.32	.88
CO MASS GRAMS	30.43	1.76	11.54
CO2 MASS GRAMS	1349.8	1465.5	1174.0
NOX MASS GRAMS	2.29	1.20	1.88
THC GRAMS/MI	.66	.08	.25
CO GRAMS/MI	8.56	.46	3.25
CO2 GRAMS/MI	379.8	385.1	330.3
NOX GRAMS/MI	.64	.32	.53
FUEL ECONOMY IN MPG	22.43	22.97	26.38
RUN TIME SECONDS	505.	867.	505.
MEASURED DISTANCE MI	3.55	3.81	3.55
SCF, DRY	.986	.990	.987

COMPOSITE RESULTS

TEST NUMBER	1	
BAROMETER	MM HG	749.0
HUMIDITY	G/KG	2.8
TEMPERATURE	DEG C	25.6

		3-BAG	(4-BAG)
CARBON DIOXIDE	G/MI	368.9	(.0)
FUEL ECONOMY	MPG	23.69	(.00)
HYDROCARBONS (THC)	G/MI	.25	(.00)
CARBON MONOXIDE	G/MI	2.91	(.00)
OXIDES OF NITROGEN	G/MI	.44	(.00)

SOUTHWEST RESEARCH INSTITUTE - DEPARTMENT OF EMISSIONS RESEARCH
TABLE B-4. FTP - VEHICLE EMISSIONS RESULTS -
PROJECT 08-1567-001

TEST NO. 2 RUN 2
VEHICLE MODEL 87 FORD TAURU
ENGINE 2.5 L(150. CID) L-4
TRANSMISSION A3

VEHICLE NO.2
DATE 1/26/88
BAG CART NO. 2
DYNO NO. 3
CVS NO. 2

TEST WEIGHT 1361. KG(3000. LBS)
ACTUAL ROAD LOAD 5.5 KW(7.4 HP)
GASOLINE EM-781-F
ODOMETER 46043. KM(28610. MILES)

BAROMETER 750.82 MM HG(29.56 IN HG)
RELATIVE HUMIDITY 14. PCT
DRY BULB TEMP. 21.7 DEG C(71.0 DEG F)
ABS. HUMIDITY 2.3 GM/KG
NOX HUMIDITY CORRECTION FACTOR .78

BAG RESULTS

BAG NUMBER	1	2	3
DESCRIPTION	COLD TRANSIENT	STABILIZED	HOT TRANSIENT
BLOWER DIF P MM. H2O(IN. H2O)	787.4 (31.0)	787.4 (31.0)	787.4 (31.0)
BLOWER INLET P MM. H2O(IN. H2O)	787.4 (31.0)	787.4 (31.0)	787.4 (31.0)
BLOWER INLET TEMP. DEG. C(DEG. F)	44.4 (112.0)	41.7 (107.0)	43.3 (110.0)
BLOWER REVOLUTIONS	40495.	69677.	40551.
TOT FLOW STD. CU. METRES(SCF)	75.9 (2682.)	131.3 (4637.)	76.2 (2690.)
THC SAMPLE METER/RANGE/PPM	53.8/ 2/ 54.	8.7/ 2/ 9.	25.1/ 2/ 25.
THC BCKGRD METER/RANGE/PPM	4.1/ 2/ 4.	4.1/ 2/ 4.	3.8/ 2/ 4.
CO SAMPLE METER/RANGE/PPM	80.2/14/ 381.	10.6/12/ 11.	54.6/13/ 129.
CO BCKGRD METER/RANGE/PPM	.3/14/ 1.	.9/12/ 1.	.4/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	97.3/14/1.0654	80.0/14/ .6612	92.2/14/ .9221
CO2 BCKGRD METER/RANGE/PCT	12.1/14/ .0420	12.1/14/ .0420	12.1/14/ .0420
NOX SAMPLE METER/RANGE/PPM	93.0/ 1/ 23.2	25.4/ 1/ 6.4	61.0/ 1/ 15.3
NOX BCKGRD METER/RANGE/PPM	1.6/ 1/ .4	1.8/ 1/ .5	1.5/ 1/ .4
DILUTION FACTOR	12.09	20.21	14.30
THC CONCENTRATION PPM	50.	5.	22.
CO CONCENTRATION PPM	371.	10.	125.
CO2 CONCENTRATION PCT	1.0269	.6213	.8830
NOX CONCENTRATION PPM	22.8	6.0	14.9
THC MASS GRAMS	2.20	.37	.96
CO MASS GRAMS	32.76	1.48	11.12
CO2 MASS GRAMS	1427.9	1493.7	1231.8
NOX MASS GRAMS	2.60	1.18	1.70
THC GRAMS/MI	.62	.10	.27
CO GRAMS/MI	9.19	.38	3.11
CO2 GRAMS/MI	400.8	386.5	344.2
NOX GRAMS/MI	.73	.30	.48
FUEL ECONOMY IN MPG	21.26	22.89	25.34
RUN TIME SECONDS	504.	868.	505.
MEASURED DISTANCE MI	3.56	3.86	3.58
SCF, DRY	.986	.989	.987

COMPOSITE RESULTS

TEST NUMBER 2
BAROMETER MM HG 750.8
HUMIDITY G/KG 2.3
TEMPERATURE DEG C 21.7

		3-BAG	(4-BAG)
CARBON DIOXIDE	G/MI	377.9	(.0)
FUEL ECONOMY	MPG	23.14	(.00)
HYDROCARBONS (THC)	G/MI	.25	(.00)
CARBON MONOXIDE	G/MI	2.95	(.00)
OXIDES OF NITROGEN	G/MI	.44	(.00)

APPENDIX C

COMPUTER PRINTOUTS OF REGULATED EMISSIONS AND FUEL ECONOMY VOIDED TEST RESULTS

Table C-	Vehicle	Test No.	Run No.	Test Problem
1	Taurus	2	1	vehicle died during hot-start
2	Camaro	1	1	incomplete 1,3-butadiene data

SOUTHWEST RESEARCH INSTITUTE - DEPARTMENT OF EMISSIONS RESEARCH
TABLE C-1. FTP - VEHICLE EMISSIONS RESULTS -
PROJECT 08-1567-001

TEST NO. 2 RUN 1
VEHICLE MODEL 87 FORD TAURU
ENGINE 2.5 L(150. CID) L-4
TRANSMISSION A3

VEHICLE NO.2
DATE 1/25/88
BAG CART NO. 2
DYNO NO. 3
CVS NO. 2

TEST WEIGHT 1361. KG(3000. LBS)
ACTUAL ROAD LOAD 5.5 KW(7.4 HP)
GASOLINE EM-781-F
ODOMETER 46026. KM(28599. MILES)

BAROMETER 755.14 MM HG(29.73 IN HG)
RELATIVE HUMIDITY 13. PCT
DRY BULB TEMP. 23.9 DEG C(75.0 DEG F)
ABS. HUMIDITY 2.4 GM/KG
NOX HUMIDITY CORRECTION FACTOR .78

BAG RESULTS

BAG NUMBER	1	2	3
DESCRIPTION	COLD TRANSIENT	STABILIZED	HOT TRANSIENT
BLOWER DIF P MM. H20(IN. H20)	762.0 (30.0)	762.0 (30.0)	762.0 (30.0)
BLOWER INLET P MM. H20(IN. H20)	762.0 (30.0)	762.0 (30.0)	762.0 (30.0)
BLOWER INLET TEMP. DEG. C(DEG. F)	45.6 (114.0)	42.2 (108.0)	43.3 (110.0)
BLOWER REVOLUTIONS	40697.	69669.	40804.
TOT FLOW STD. CU. METRES(SCF)	77.2 (2727.)	132.5 (4678.)	77.1 (2721.)
THC SAMPLE METER/RANGE/PPM	45.7/ 2/ 46.	7.9/ 2/ 8.	66.2/ 2/ 67.
THC BCKGRD METER/RANGE/PPM	3.3/ 2/ 3.	3.6/ 2/ 4.	3.9/ 2/ 4.
CO SAMPLE METER/RANGE/PPM	65.6/14/ 299.	12.0/12/ 12.	52.5/14/ 231.
CO BCKGRD METER/RANGE/PPM	.0/14/ 0.	.0/12/ 0.	.0/14/ 0.
CO2 SAMPLE METER/RANGE/PCT	96.9/14/1.0532	80.2/14/ .6648	90.9/14/ .8894
CO2 BCKGRD METER/RANGE/PCT	11.4/14/ .0392	11.6/14/ .0400	11.6/14/ .0400
NOX SAMPLE METER/RANGE/PPM	68.8/ 1/ 17.2	22.2/ 1/ 5.7	53.7/ 1/ 13.5
NOX BCKGRD METER/RANGE/PPM	.4/ 1/ .1	.6/ 1/ .2	.6/ 1/ .2
DILUTION FACTOR	12.33	20.10	14.59
THC CONCENTRATION PPM	43.	5.	63.
CO CONCENTRATION PPM	292.	12.	226.
CO2 CONCENTRATION PCT	1.0172	.6268	.8522
NOX CONCENTRATION PPM	17.1	5.5	13.3
THC MASS GRAMS	1.91	.35	2.79
CO MASS GRAMS	26.24	1.85	20.29
CO2 MASS GRAMS	1438.1	1520.3	1202.2
NOX MASS GRAMS	1.99	1.09	1.54
THC GRAMS/MI	.54	.09	.79
CO GRAMS/MI	7.42	.48	5.72
CO2 GRAMS/MI	406.8	398.5	339.0
NOX GRAMS/MI	.56	.29	.43
FUEL ECONOMY IN MPG	21.11	22.19	25.30
RUN TIME SECONDS	506.	868.	506.
MEASURED DISTANCE MI	3.54	3.81	3.55
SCF, DRY	.986	.990	.988

COMPOSITE RESULTS

TEST NUMBER 2
BAROMETER MM HG 755.1
HUMIDITY G/KG 2.4
TEMPERATURE DEG C 23.9

		3-BAG	(4-BAG)
CARBON DIOXIDE	G/MI	383.9	(.0)
FUEL ECONOMY	MPG	22.72	(.00)
HYDROCARBONS (THC)	G/MI	.38	(.00)
CARBON MONOXIDE	G/MI	3.36	(.00)
OXIDES OF NITROGEN	G/MI	.38	(.00)

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SOUTHWEST RESEARCH INSTITUTE - DEPARTMENT OF EMISSIONS RESEARCH
TABLE C-2. FTP - VEHICLE EMISSIONS RESULTS -
PROJECT 08-1567-001

TEST NO. 1 RUN 1
VEHICLE MODEL 86 CAMARO
ENGINE 2.8 L(171. CID) L-6
TRANSMISSION A4

VEHICLE NO. 1
DATE 1/19/88
BAG CART NO. 2
DYNO NO. 3
CVS NO. 2

TEST WEIGHT 1588. KG(3500. LBS)
ACTUAL ROAD LOAD 6.3 KW(8.4 HP)
GASOLINE EM-781-F
ODOMETER 53242. KM(33083. MILES)

BAROMETER 735.33 MM HG(28.95 IN HG)
RELATIVE HUMIDITY 28. PCT
DRY BULB TEMP. 23.9 DEG C(75.0 DEG F)
ABS. HUMIDITY 5.4 GM/KG
NOX HUMIDITY CORRECTION FACTOR .85

BAG RESULTS

BAG NUMBER	1	2	3
DESCRIPTION	COLD TRANSIENT	STABILIZED	HOT TRANSIENT
BLOWER DIF P MM. H2O(IN. H2O)	774.7 (30.5)	774.7 (30.5)	774.7 (30.5)
BLOWER INLET P MM. H2O(IN. H2O)	774.7 (30.5)	774.7 (30.5)	774.7 (30.5)
BLOWER INLET TEMP. DEG. C(DEG. F)	44.4 (112.0)	40.6 (105.0)	42.2 (108.0)
BLOWER REVOLUTIONS	40573.	69655.	40523.
TOT FLOW STD. CU. METRES(SCF)	74.5 (2630.)	128.8 (4546.)	74.7 (2637.)
THC SAMPLE METER/RANGE/PPM	71.5/ 2/ 72.	10.1/ 2/ 10.	31.5/ 2/ 32.
THC BCKGRD METER/RANGE/PPM	6.2/ 2/ 6.	5.7/ 2/ 6.	5.0/ 2/ 5.
CO SAMPLE METER/RANGE/PPM	86.9/14/ 421.	64.8/12/ 65.	73.5/14/ 343.
CO BCKGRD METER/RANGE/PPM	1.1/14/ 4.	2.8/12/ 3.	.8/14/ 3.
CO2 SAMPLE METER/RANGE/PCT	94.1/14/ .9725	81.6/14/ .6904	89.9/14/ .8652
CO2 BCKGRD METER/RANGE/PCT	13.3/14/ .0468	13.3/14/ .0468	13.1/14/ .0460
NOX SAMPLE METER/RANGE/PPM	86.7/ 1/ 21.7	16.0/ 1/ 4.1	40.1/ 1/ 10.1
NOX BCKGRD METER/RANGE/PPM	2.6/ 1/ .7	1.3/ 1/ .3	.8/ 1/ .2
DILUTION FACTOR	13.13	19.20	14.86
THC CONCENTRATION PPM	66.	5.	27.
CO CONCENTRATION PPM	405.	61.	331.
CO2 CONCENTRATION PCT	.9232	.6460	.8223
NOX CONCENTRATION PPM	21.1	3.8	9.9
THC MASS GRAMS	2.83	.36	1.17
CO MASS GRAMS	35.16	9.12	28.77
CO2 MASS GRAMS	1367.1	1522.9	1124.2
NOX MASS GRAMS	2.55	.79	1.20
THC GRAMS/MI	.79	.09	.33
CO GRAMS/MI	9.85	2.36	8.09
CO2 GRAMS/MI	354.9	394.7	316.1
NOX GRAMS/MI	.71	.21	.34
FUEL ECONOMY IN MPG	23.78	22.24	26.88
RUN TIME SECONDS	505.	868.	505.
MEASURED DISTANCE MI	3.57	3.86	3.56
SCF, DRY	.982	.984	.983

COMPOSITE RESULTS

TEST NUMBER 1
BAROMETER MM HG 735.3
HUMIDITY G/KG 5.4
TEMPERATURE DEG C 23.9

		3-BAG	(4-BAG)
CARBON DIOXIDE	G/MI	365.0	(.0)
FUEL ECONOMY	MPG	23.67	(.00)
HYDROCARBONS (THC)	G/MI	.30	(.00)
CARBON MONOXIDE	G/MI	5.48	(.00)
OXIDES OF NITROGEN	G/MI	.35	(.00)

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